Evaluation of Blue Confirmation Lights on Red Light Running at Signalized Intersections in Lawrence, Kansas: A Case Study

By

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Date approved: July 22, 2014

DEDICATION

This thesis is dedicated to my parents, Kwaku Adu Frimpong and Juliana Kumi Darkowaa.

I could not have made it this far without you. God bless you.

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ABSTRACT

Red light running (RLR) continues to be a safety concern for many communities in the United States. The Insurance Institute for Highway Safety reported in 2012 that RLR resulted in 683 fatalities and an estimated 133,000 injuries nationwide. Currently, a wide range of countermeasures from low-cost strategies (e.g. signal timing adjustments, signal backplates, signage improvements, and targeted enforcement) to high-cost strategies (e.g. automated enforcement, lighted stop bar systems and intersection geometric improvements) exists to mitigate RLR violations and their related crashes.

The severity of RLR crashes and high societal cost (about 14 billion dollars annually) have provided the impetus for increased red light enforcement programs throughout the country. In the State of Kansas, where automated red light cameras are not authorized, communities rely on targeted traffic law enforcement. Traditionally, red light enforcement has required a police officer to be located upstream of an intersection to observe the violation and another officer located downstream to pullover the offender and issue a ticket. This enforcement approach is labor intensive. In locations where enforcement resources are limited, having a single police officer monitor RLR raises intersection safety concerns. Confirmation light systems can aid a single police officer located downstream of an intersection to monitor RLR violations without having to travel through an intersection to pullover the offender.

The city of Lawrence installed confirmation lights at six left-turn approaches of two signalized intersections (treatment sites) where RLR was prevalent. This study was conducted to evaluate the effectiveness of the confirmation lights. RLR violation data were collected before, one and three months after installation of the lights at the two treatment sites and 11 non-treated intersections which included six spillover sites (intersections nearby the treatment sites) and five

control sites (intersections located far from the treatment sites or corridor under investigation). A Z test of proportion was used to determine if the changes in RLR violation rates from the before period to the after periods were statistically significant at the 95 percent level of confidence. The violation rates at the two treated sites were then compared to non-treated sites. Violation time into red (how long it took a driver to run a red light after red signal indication) was used as a secondary performance matrix to evaluate the confirmation lights. A Chi Square Test of Independence was used to analyze the violation times into red at the 95 percent level of confidence.

Results of the analysis showed a 57.4 percent reduction in left-turn RLR violation rates at the treatment sites and a 55.7 percent reduction at the spillover sites one month after installation of the confirmation lights. The three months after study indicated a 42.7 percent decrease in violation rates at the treatment sites and a 31.7 percent decrease at spillover sites. Considering RLR violations in the City of Lawrence as a whole, the control sites showed no significant change in left-turn RLR violations during the study periods. Although the treatment intersections did not have confirmation lights installed for the through movement, the lights were effective in the short term for reducing RLR violations (84.1 percent reduction). The Chi Square Test showed that that the confirmation lights had no significant effect on the RLR violation times into red.

In conclusion, the findings of this research study indicated that confirmation lights (both self-enforcing and aiding police officers) have a positive effect in reducing RLR violations at targeted signalized intersections.

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CHAPTER 1: INTRODUCTION

1.1 Background

Vehicles running red lights is the leading cause of vehicle crashes at urban signalized intersections (Insurance Institute of Highway Safety (IIHS), 2013). Red light running (RLR) is a serious traffic safety issue that many communities in the United States are facing. RLR is a common event or situation where a vehicle proceeds through a signalized intersection when the red aspect of the signal is shown. In 2012, RLR resulted in 683 fatalities and an estimated 133,000 injuries nationwide (IIHS, 2013). Approximately half of the fatalities reported in 2012 were not the drivers, but were passengers, pedestrians, cyclists and other road users. The consequences of RLR crashes also have had a negative effect on the U.S. economy. According to the Federal Highway Administration (FHWA), the annual societal cost of RLR is approximately 14 billion dollars (FHWA, 2005). In 2013, the AAA Foundation for Traffic Safety (2014) conducted a survey to assess how Americans value and pursue road safety. Results of the study indicated that 93.1 percent of drivers believed running a red light was unacceptable, yet 35.2 percent of the same drivers polled admitted doing so at least once in the previous month when it was safe to stop.

Due to the seriousness of RLR, considerable efforts have been taken by states and local agencies to explore and implement strategies to reduce RLR violations and associated crashes. Currently, a wide range of countermeasures exists to mitigate RLR violations and crashes. These include low-cost strategies such as traffic signal timing adjustments, signage improvements, targeted police enforcement, public awareness campaigns, and high-cost strategies, such as improvements to the physical geometric and operational characteristics of intersection approaches, and automated enforcement. These countermeasures have been implemented across the country and previous studies have showed their measure of effectiveness (Institute of Transportation Engineers, 2003; Bonneson et al., 2004; Hallmark et al., 2012).

As of May 2014, 503 communities in the United States have red light camera programs in place to capture drivers running red lights (IIHS, 2014). However, automated red light cameras are sometimes not practical, feasible or legal in some communities. The high cost of installation, state statutes and the controversies surrounding their implementations have hindered their usage nationwide. In these circumstances, communities without automated enforcement rely on low-cost countermeasures to reduce RLR crashes at signalized intersections.

A low-cost RLR countermeasure that has been found to have limited research are confirmation lights, sometimes referred to as enforcement lights. Confirmation lights come in variety of colors. For example, Figure 1 (A) shows a white confirmation light in Florida and Figure 1 (B) shows a blue confirmation light in Kansas. This countermeasure has been deployed widely in communities located in California, Florida, and Texas (FHWA, 2009).

(A) **(B)**

Figure 1. Varieties of confirmation lights

1.2 Research Objective

The primary objective of this research study was to evaluate the effectiveness of confirmation lights at signalized intersections in Lawrence, Kansas. This objective was accomplished by conducting before and after RLR violation studies at two treated signalized intersections (where confirmation lights were installed) and 11 non-treated signalized intersections. Analysis of the RLR violations was completed with the understanding that a change (a decrease or an increase) in violation rates from the before period to the after periods would be equated to a possible reduction or an increase in crashes at signalized intersections.

1.3 Thesis Organization

This thesis is divided into seven chapters. Chapter 1, Introduction, presents a brief background of RLR and discusses some of the strategies adopted in mitigating RLR at signalized intersections. In this same chapter, the objective of this study is presented as well. Chapter 2 summarizes literature on RLR. The literature review discusses RLR definitions, characteristics of the RLR violators, RLR violation and crash rates, and explains some of the countermeasures that have been implemented and evaluated by other researchers. Chapter 3 introduces the problem statement and the need for this research. Chapter 4 outlines the methodology used in gathering and analyzing field video data from the study intersections. Chapter 5 presents descriptive statistics of the RLR violation data. Chapter 6 presents the analyses of RLR violation data using statistical methods and discusses the key findings from this research. Finally, Chapter 7 presents the general conclusions, contributions of this study to highway safety, and proposes future studies.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews current literature on RLR. It cites information from articles, technical reports, research journals and other relevant publications pertaining to RLR. The objectives of this literature review were to:

- Define RLR;
- Identify characteristics of red light runners;
- Determine how frequently drivers run red lights;
- Determine factors that contribute to RLR; and
- Explore some of the strategies that have been implemented in reducing RLR violations and associated crashes.

2.1 Red Light Running

RLR is one of the leading causes of vehicle crashes at urban signalized intersections (IIHS, 2013). The definition of RLR differs from state to state based on whether "permissive yellow" or "restrictive yellow" laws are in effect.

According to the FHWA (2013), under the "permissive yellow" rule as stated in the Manual on Uniform Traffic Control Device (MUTCD) and Uniform Vehicle Code (UVC)); "Driver can legally enter intersection during the entire yellow interval and violation occurs if driver enters intersection after onset of red. Under the "restrictive yellow" rule, driver can neither enter nor be in intersection on red and violation occurs if driver has not cleared intersection after onset of red."

In most states, vehicles that are within the intersection waiting to make a left-turn when the signal changes from yellow to red are not considered to be running a red light, and are encouraged to clear the intersection. At intersections where a right-turn on red is permitted, a vehicle must come to a complete stop; failure to do so is also considered a violation (IIHS, 2013).

2.2 Frequency of Red Light Running

The AAA Foundation for Traffic Safety conducted a national survey in 2013 to assess the degree to which Americans value and pursue traffic safety. A sample size of 3,103 U.S. residents aged 16 years and older was asked to complete a web-based survey for this study. It was found that approximately 93 percent of drivers considered RLR as an aggressive and unacceptable way of driving. However, 35 percent of the same drivers admitted doing so when it was safe to stop at least once in the previous month (AAA Foundation for Traffic Safety, 2014).

McCartt and Eichelberge (2011) conducted a study to evaluate the attitudes of motorists towards red light camera programs in 15 cities in the United States. A sample size of 3,411 drivers participated in the telephone survey study. Results of the study indicated that 82 percent of the drivers said running a red light was a serious threat to their personal safety, and 93 percent said it was unacceptable to society.

Hill and Lindly (2003) performed a study to develop models in predicting RLR violation rates at four-leg intersections based on their traffic operational and geometry characteristics. They collected RLR violation data at 19 study intersections in four states (Alabama, California, Iowa, and Texas) for a period of six hours on weekdays (2 p.m. to 8 p.m.). They observed 1,775 violations in 554 hours representing a rate of 3.2 violations per hour per intersection.

Retting et al. (1998) conducted a study to analyze RLR violation data at two busy intersections equipped with red light cameras in Arlington, Virginia. They collected data between November 1994 and 1995. The study found a total of 8,121 RLR violations over a period of 2,694 hours, representing an average of 3.0 red light runners per hour (Retting et al., 1998).

2.3 Characteristics of Red Light Runners

Porter et al. (1999) conducted a telephone survey study to identify red light runners and their characteristics. Out of the 5,024 respondents who completed the survey, 4,007 were concentrated in ten target states and 1,017 in the remaining 40 states. Based on national data, the authors concluded that a driver running a red light was more likely to be:

- A younger driver;
- A driver without a child or children (less than 20 years old);
- Driving alone;
- In a rush to school or work in the morning on weekdays;
- Unemployed or employed in jobs requiring less education;
- Driving more than two miles from home; and
- Previously ticketed for RLR.

Retting and Williams (1996) also conducted a similar study to investigate the behavior of red light runners in Arlington, Virginia. They asked trained observers to collect RLR violation data at an intersection equipped with red light enforcement cameras. During each cycle length, the observers recorded the characteristics of the drivers that ran the red lights and the type of vehicles they were driving. Out of 1,373 observations, the observers recorded 462 RLR violations at the study location. Findings from their study indicated that red light runners generally were drivers below 30 years of age, who drove small cars and had multiple convictions for speeding and moving violations. They also found out that violations were common for drivers with car models manufactured after 1991 and the drivers were less likely to be wearing seat belts.

Retting et al. (1999c) extracted data from the Fatality Analysis Reporting System (FARS, 1992 to 1996) and the General Estimates System (GES) to review the characteristics of red light runners. They found that red light runners were more likely to be a male driver under 30 years of age, more likely to have been ticketed for moving violations and more likely to have been convicted for driving while intoxicated. The authors also found that the violators were more likely to run red lights in the nighttime than in the daytime, and 53 percent of such drivers were believed to have a high blood alcohol concentration.

2.4 Factors Contributing to Red Light Running

In the previous section, it was found that a majority of the RLR violations and crashes were human related. However, many studies have identified other contributing factors that lead to the frequency of RLR.

Traffic operation characteristics such as approach volume and speed and intersection features such as signal timing, approach grade, and sight distance affect drivers' behavior as they approach an intersection. Additionally, environmental factors such as time of day and weather conditions may also influence driving behavior (Yang and Najm, 2006). Table 1 explains how intersection, traffic and environmental factors contribute to the frequency of RLR.

Table 1. Intersection, Traffic and Environmental Factors to RLR (Yang and Najm, 2006)

Element	Variable	Key Finding	Reference
Intersection	Signal Timing	The frequency of RLR increases when the yellow interval is less than 3.5 seconds.	*Brewer et al., 2002*
		Longer yellow intervals will cause drivers to enter intersection later and lengthening the all-red intervals caters to red light violators.	*Eccles and McGee, 2000*
	Stopping Distance	Probability of a vehicle stopping for traffic signal decreases as its distance from the intersection decreases.	*Chang et al., 1985*
	Approach Speed	Probability of a driver stopping for traffic signal decreases as the approach speed to the intersection increases.	*Chang et al., 1985*
	Grade	Probability of a driver stopping for traffic signal increases as the approach grade to the intersection increases.	*Chang et al., 1985*
	Intersection Width	Drivers tend to stop for traffic lights more at wider intersections than at narrower intersections.	*Chang et al., 1985*
Traffic & Environment	Approach Volume	Higher red light running rates are observed in cities with wider intersections and higher traffic volumes.	*Porter and England, 2000*
		The RLR frequency increases as the approach traffic volume at intersection increases.	*Brewer et al., 2002*
	Time of Day	Higher red light violations occur during the time period of 3:00 p.m. to 5:00 p.m.	*Kamyab et al.,2002; Kamyab et al.,2000*
		The average number red light violations are higher during a.m. and p.m. peak hours compared to other times of the day.	*Retting et al.,1998*
	Day of the week	There are more red light violations on weekdays compared to weekends.	*Lum and Wong,2003; Kamyab et al., 2002; Kamyab et al., 2000; Retting et al., 1998*
	Weather	The influence of rainfall on RLR behavior is not significant.	*Retting et al.,1998*

Poor visibility as a result of obstructions from overhanging vegetation, billboards, large trucks, commercial sign, low pressure sodium lights, bad design of the intersection alignments, parked vehicles and pedestrians can be a major factor that influence drivers' stop-go decisions at intersections. Clearing these obstacles enhance safety and traffic operations at intersections (FHWA, 2005).

2.5 Red Light Running Countermeasures

Successful RLR countermeasures including engineering, education and enforcement, and have been implemented in many communities across the United States. Studies have been conducted to investigate the effectiveness of these countermeasures and sometimes results showed a positive effect in reducing RLR violations and associated crashes. Prior to implementation of any of the countermeasures, studies investigating possible causes of red light running should be carried out and then appropriate countermeasures be selected to mitigate the problem (Bonneson et al., 2004).

Table 2 shows the possible causes of RLR and correlates the appropriate countermeasures that are likely or could address the cause (Hallmark et al., 2012).

Table 2. Possible Causes and Appropriate Countermeasures for RLR (Hallmark et al., 2012)

Possible Causes of RLR	Engineering Countermeasures			Enforcement
	Signal Operation	Motorist Information	Physical Improvement	
Congestion or excessive delay	•		•	
Disregard for red				•
Judged safe due to low conflicting volume			•	•
Judged safe due to narrow cross street				•
Judged safe due to following < 2 sec behind vehicle infront				•
Expectation of green when in platoon	•			
Downgrade steeper than expected	•			
Speed higher than posted limit	•			
Unable to stop (excessive deceleration)	•			
Pressured by closely following vehicle	•			
Tall vehicle ahead blocked view		•		
Unexpected, first signal encountered		•		
Not distracted, just did not see signal		•		
Distracted and did not see traffic signal		•		
Restricted view of signal		•	•	
Confusing signal display		•		

- Indicates the appropriate countermeasure

2.6 Engineering Countermeasures

From the literature, engineering countermeasures are generally categorized into three groups: signal operation countermeasures, motorist information countermeasures, and physical improvement countermeasures (Bonneson et al., 2004). Signal operation countermeasures involve the modifications or adjustments of the timing of the signal phases, and change in cycle interval. With motorist information countermeasures, drivers are provided with advance information about existing traffic signals ahead for drivers to respond appropriately as they approach an intersection. Physical improvement countermeasures involve the redesign of intersections to increase vehicle operational characteristics. Table 3 shows the three countermeasure categories with specific engineering countermeasure to reduce RLR.

Table 3. Engineering Countermeasures to Red Light Running

<table>
<tr><th>Countermeasure Category</th><th colspan="2">RLR Countermeasure</th></tr>
<tr><td rowspan="4">Signal Operation</td><td colspan="2">Yellow change interval</td></tr>
<tr><td colspan="2">Green extension</td></tr>
<tr><td colspan="2">Signal operation and coordination</td></tr>
<tr><td colspan="2">All red clearance interval</td></tr>
<tr><td rowspan="12">Motorist Information</td><td colspan="2">Improve sight distance</td></tr>
<tr><td rowspan="3">Improve signal visibility</td><td>Placement and number of signal heads</td></tr>
<tr><td>Size of signal display</td></tr>
<tr><td>Line of sight</td></tr>
<tr><td rowspan="5">Improve signal conspicuity</td><td>Redundancy</td></tr>
<tr><td>LEDs signal lenses</td></tr>
<tr><td>Backplates</td></tr>
<tr><td>Lighted Stop Bar Systems</td></tr>
<tr><td>LED outlined backplates.</td></tr>
<tr><td rowspan="3">Advance warning signs</td><td>Signal ahead signs</td></tr>
<tr><td>Advance warning flashers</td></tr>
<tr><td>Rumble strips</td></tr>
<tr><td rowspan="4">Physical Improvements</td><td colspan="2">Remove unwanted signals</td></tr>
<tr><td colspan="2">Add capacity with additional traffic lanes</td></tr>
<tr><td colspan="2">Improve the geometry (vertical and horizontal curves)</td></tr>
<tr><td colspan="2">Convert signalized intersection to roundabout intersection</td></tr>
</table>

2.6.1 Signal Operation

2.6.1.1 Yellow Change Interval

Most RLR violations occur less than two seconds after the onset of the red light (Washburn, 2004). This means that increasing the yellow signal time could aid drivers in safely clearing the intersection prior to the onset of red signal. Retting et al. (2007) conducted a before-after comparison study to determine the effects of lengthening the yellow change time interval at two study intersections in Philadelphia, Pennsylvania. The yellow time was increased by one second, followed by red light camera enforcement several months later. They conducted similar study at comparison intersections without any treatment. Results of their study showed a 36 percent reduction in violations when the yellow change interval was increased by one second. With the addition of red light enforcement, they observed a further reduction in RLR violations by 96 percent beyond the implemented yellow time change.

The MUTCD provides guidance with regards to minimum and maximum yellow interval. It recommends a minimum yellow change interval of three seconds and a maximum of six seconds. It also suggests that longer intervals should be reserved for use on approaches with higher speeds (MUTCD, 2009). The Traffic Engineering Handbook, 6th Edition (2009), recommends Equation 1 be used to calculate the appropriate yellow time for any signalized intersection approach. However, it cautions that maximum care should be used when the interval time chosen is more than five seconds. McGee et al. (2012) in their research study did not find any reason to suggest a minimum or maximum yellow interval.

$$\boldsymbol{y = t + \left[\frac{v}{2a + 2Gg}\right]} \qquad \textbf{Eq. 1}$$

where y = yellow clearance interval (sec);

t = reaction time (typically 1 sec);

v = design speed (ft/sec^2);

a = deceleration rate (typically 10 ft/sec^2);

g = acceleration due to gravity (32 ft/sec^2); and

G = grade of approach (percent/100, downhill is negative grade).

2.6.1.2 All-Red Clearance Interval

An all-red phase is defined as when all the approaches at an intersection have a red-signal display for a very short period of time. If a vehicle enters an intersection without all-red interval at the end of the yellow phase, it is more likely to result in a crash when vehicles in conflicting approaches receive a green light (McGee et al., 2003).

Schattler et al. (2003) conducted a study at three signalized intersections in Oakland County, Michigan. The purpose of the study was to evaluate the impact of all-red clearance intervals on RLR violations and the late exit of vehicles within the intersections when the red light was indicated. They used video cameras to collect data before and after the implementation of the clearance intervals. They found that the implementation of all-red clearance intervals which ranged from two to three seconds significantly reduced the risk of late exiting of vehicles being struck by opposing traffic streams that have a green signal.

According to the MUTCD (2009), "Except when clearing a one-lane, two-way facility or when clearing an exceptionally wide intersection, a red clearance interval should have a duration not exceeding 6 seconds." However, in the Traffic Engineering Handbook, 6th Edition (2009), it is suggested that equation 2 should be used to calculate the appropriate all-red clearance interval. McGee et al. (2012) also recommended a minimum of one second time to be used for all-red clearance intervals. They suggested that providing additional time for vehicles that are legally in an intersection at the onset of red light allows drivers to clear the intersection in order to avoid conflict with adjacent traffic stream with a given green light.

$$\boldsymbol{R = (w/L)/v} \qquad \textbf{Eq. 2}$$

where R = all red interval (sec);

w = width of stop line to far side non-conflict point (ft);

v = design speed (ft/sec); and

L = length of vehicle.

2.6.1.3 Green Extension

Green-extension systems (GES) extend the green phase of traffic signals before the yellow aspect of the signal is shown. This allows a vehicle or platoon of vehicles to clear the intersection before the yellow indication is shown. With this technology, advance detectors are deployed on major roads at actuated-signaled intersection approaches to change the signal phase or increase the green time when a vehicle passes over them. Approaches are cleared of vehicles that might have been in the dilemma zone until the green phase is maxed-out.

Zegeer and Deen (1978) conducted a study to evaluate how GES could reduce RLR crashes at three signalized intersections in Kentucky. They used about nine years of before crash data and about four years of crash data after the installation of the GES at the three study sites. Results of their study showed 54 percent reduction in total crashes.

2.6.1.4 Signal Operation and Coordination

Two or more adjacent signalized intersections are sometimes coordinated to move platoons of vehicles along a corridor in order to minimize delays and increase traffic flow. At isolated locations where signalized intersections are not in coordination, it may result in excessive delays and impatient drivers may violate a red light when they arrive at an intersection near the end of the green interval (Bonneson et al., 2002). For this reason, adjacent intersections should be coordinated so that the likelihood of drivers running a red light is minimized. Changes in signal phasing or cycle length can also reduce delays which potentially may reduce the frequency of RLR (Bonneson et al., 2002).

2.6.2 Motorist Information

The common reason drivers give for frequently running a red light is that "I did not see the signal" (McGee et al., 2003). Poor signal visibility and conspicuity, lack of advance warning signs and inadequate sight distance at signalized intersections influence driving behavior (Fitzsimmons et al., 2007).

2.6.2.1 Improve Signal Visibility

The positioning of signals either overhead or pole-mounted impacts driving behavior. An overhead signal display provides a clear meaning, good visibility, and eliminates the blockage of drivers' line-of-sight to the signal head when tall vehicles such as trucks are present in the traffic stream.

Schattler et al. (2011) investigated how different signal mounting configurations affect RLR at urban signalized intersections in Illinois and Michigan. The researchers focused on three types of signal mounting configurations: mast arm, diagonal span wire and near-side/far-side post mount. They collected data at 12 study intersections looking for red light runners and yellow light runners (YLR) using video cameras. Data collections were for three hours (noon to 3 p.m.) on weekdays in the spring and summer of 2007. A comparative parallel analysis of their data showed a significantly fewer RLR and YLR at the intersections with mast arm configurations than at intersections with span wire configurations. At the near-side/far-side post mounted signalized intersections, the authors found a higher rate of RLR and YLR. Their study showed that post-mounted configurations reduced the visibility of signal heads, which may result in an increase in the frequency of RLR.

When considering the location to mount a signal at an intersection, a driver's line of sight is a critical factor that should not be overlooked. The closer the signal heads are installed to a driver's line of sight, the more visible the signal heads become.

2.6.2.2 Improve Signal Conspicuity

Another technique for making signal heads conspicuous is to use retroreflective materials on the borders of backplates as shown in Figure 2.

Figure 2. Retroreflective backplate border (FDOT, 2014)

The MUTCD (Section 4D.18) requires the front surface of the backplate to have a dull black finish "to minimize light reflection and to increase contrast between the signal indication and its background." Research has shown that signal head backplates have the effect of reducing the frequency of crashes at intersections by 32 percent (Bonneson et al., 2002). In 2010, the FHWA reported a before-after study at three intersections in Columbia, South Carolina, on the effectiveness of retroreflective borders on the backplates. The study found a 28.6 percent reduction in total crashes, 36.7 percent reduction in injury crashes and 49.6 percent in late-night/early-morning crashes. (FHWA, 2010)

For intersections where visibility is a problem, using redundant signal heads is a means of improving the conspicuity of the signals. The MUTCD (2009) illustrates various configurations of redundant signal heads that have shown to be effective at signalized intersections. Figure 3 illustrates different configurations of two red signal heads from the MUTCD. A study in Winston-Salem, North Carolina, found a 33.1 percent significant reduction in RLR right-angle crashes when nine study intersections were equipped with redundant signal heads (Polanis, 2002).

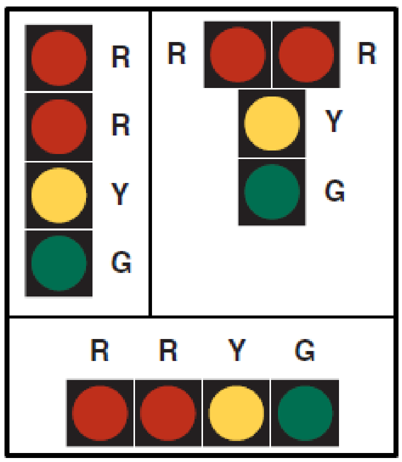

Figure 3. Redundant red light signal configurations (MUTCD 2009)

Lighted Stop Bar Systems (LSBS) and Light Emitting Diode (LED) outlined backplates have shown to be effective in reducing RLR at signalized intersections. LSBS consists of markers installed into the pavement along the stop line of an intersection. The markers contain LED lights which activates during the red signal indication of the traffic light. LED outlined backplate also consists of LEDs placed around the perimeter of a signal backplate. The LEDs emit light during the red signal indication of the traffic light to gain the attention of drivers approaching the intersection. Active operation of the LSBS and LED outlined backplates are shown in Figure 4 and Figure 5, respectively.

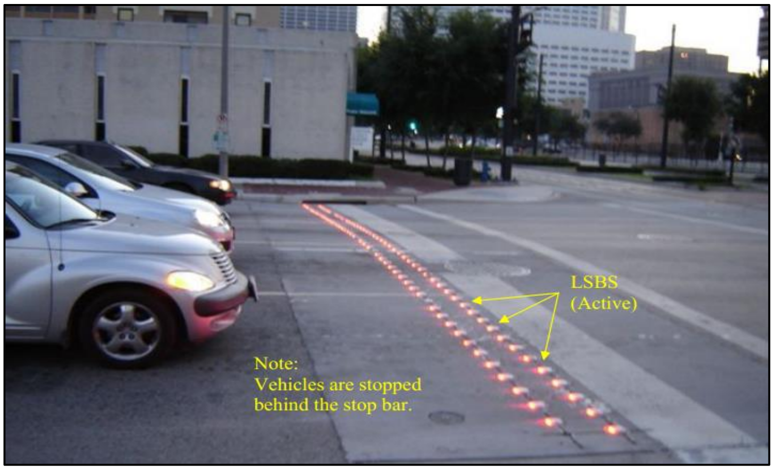

Figure 4. Lighted stop bar system (active) in Houston, Texas (Tydlacka et al., 2011)

Figure 5. LED backplate (Active) in Houston, Texas (Tydlacka et al., 2011)

Tydlacka et al. (2011) conducted a study at two signalized intersections in Houston, Texas to evaluate the effectiveness of these supplemental traffic control devices. They collected data using video cameras three days before and three days after the installation of the LED backplates and LSBS separately at the two study intersections. They found a statistically significant reduction of RLR violations from 21.8 to 11.2 violations per day per 10,000 vehicles at the site where the LED blackplates were installed. At the intersection with LSBS, they found a reduction in RLR violations from 12.9 to 11.3 violations per day per 10,000 vehicles. That was found to be not statistically significant.

2.6.2.3 Advance Warning Signs

Advance warning signs gain the attention of road users to unexpected roadway conditions that might be not readily apparent to them. According to the MUTCD (2009), the "Signal Ahead" sign (W3-3) shown in Figure 6 can be used to alert derivers of the presence of a signalized intersection ahead.

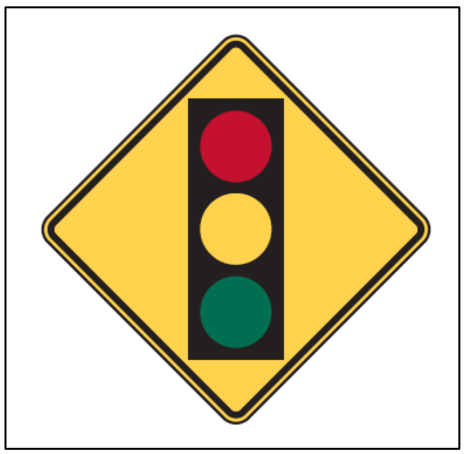

Figure 6. Signal Ahead sign, W3-3 (MUTCD 2009)

Polanis (2002) analyzed a before-after crash data (36 to 48 months) from collision diagrams prepared by police department in the city of Winston–Salem, North Carolina, to evaluate the effectiveness of eight engineering countermeasures to reduce RLR. A before-after study of "Signal Ahead" signs was one of the strategies evaluated. It was found that installation of the "Signal Ahead" sign at 11 study locations showed a 44 percent reduction in right angle crashes.

Another type of advance warning sign is the "Be Prepared To Stop" sign (W3-4) as shown in Figure 7. Flashing beacons and "When flashing" plaques (W16-13P) shown in Figure 8 can be added to this sign to alert drivers that the green light is about to change to red in few seconds (MUTCD 2009).

Figure 7. Be prepared to stop sign, W3-4 (MUTCD 2009)

Figure 8. "Be prepared to stop" sign supplemented with flashing beacons and when flashing plaque (MUTCD 2009)

Messer et al. (2004) performed a two year study to evaluate how the Advance Warning for End-of-Green Systems (AWEGS), could reduce RLR violations at two high speed intersections in Texas. Red light runners were detected at the study sites by using "video imaging vehicle detection systems" (VIVDS). Prior to the installation of the systems, they collected data for two weeks. After installation of AWEGS, they collected data for 35 days for the first phase of their study followed by the second phase where data were collected for 21 days. Results of their field evaluations showed that AWEGS reduced RLR violations within five seconds of the onset of the red light indication by 40 to 45 percent. Figure 9 shows the design features and layout of the AWEGS.

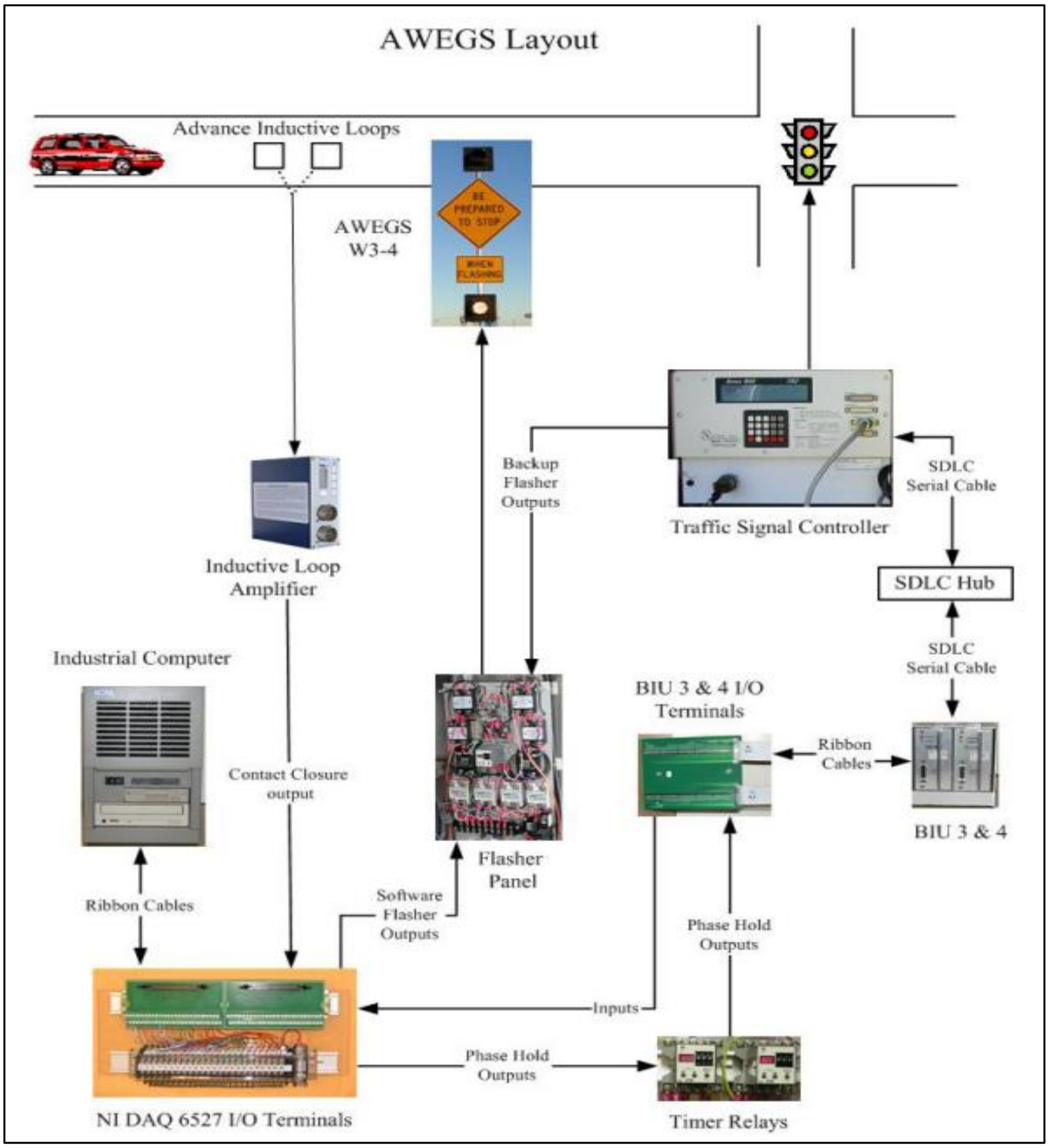

Figure 9. Design features and layout of AWEGS (Messer et al., 2004)

2.6.3 Physical Improvements

At low-volume intersections where traffic signals are unwarranted, removing the signals can be an effective measure to reducing crashes at such locations provided the safety and the operational characteristics of the intersections are not compromised. Before traffic signals are installed at any intersection, warrant studies should be conducted based on pedestrian volumes, traffic volumes and safety measures at the intersection. A study in Philadelphia showed that the removal of unwanted signals at 199 low-volume intersections contributed to a crash reduction of 24 percent at those intersections (Retting et al., 1998).

Additional traffic lanes for maneuvering through or making right-turns or left-turns at signalized intersections is an effective measure of reducing congestion. Most traffic delays occur at intersections and when drivers stay in queues for longer periods, they might run red lights to avoid waiting for the next cycle. When additional lanes are added to intersections to increase their capacity, the problem of congestion will be reduced.

A modern roundabout is another alternative to reduce the severity of a crash such as right-angle that are common at signalized intersections. Converting a signalized intersection into a roundabout has shown to increase safety.

In NCHRP Report 572-Roundabouts in the United States, Rodegerdts et al. (2007) found a 48 percent reduction in all crash types and a 77.7 percent reduction in injury and fatal crashes when nine signalized intersections were converted to a roundabout. Persaud et al. (2001) performed a study to evaluate the change in vehicle crashes when 23 signalized or stop-controlled intersections were converted to roundabouts at urban, suburban and rural locations in the United States. They performed a before-after Empirical Bayes analysis of the data they gathered. Results of their study showed a 40 percent reduction of all crash types and an 80 percent reduction of all injury crashes at the 23 intersections combined.

2.7 Enforcement Countermeasures.

Enforcement countermeasures are those that include the use of a police officer, or a device which acts as a surrogate to a police officer. Several studies have been conducted to investigate the effectiveness of these two countermeasures or combination of the countermeasures in reducing RLR at signalized intersections.

2.7.1 Automated Enforcement

Automated enforcement is a highly effective way of using cameras to enforce RLR at signalized intersections. As of May 2014, 503 communities in the United States had red light camera programs (IIHS, 2014).

Several studies have shown that using automated enforcement is an effective tool in reducing RLR violations and associated crashes at signalized intersections. Fitzsimmons et al. (2007) found 44 percent, 90 percent and 40 percent reductions in total, right-angle and rear-end crashes, respectively, in a study they conducted in Council Bluffs, Iowa. Similarly, a study conducted in North Carolina at red light camera equipped intersections showed a 17 percent reduction in total crashes, 22 percent reduction in RLR related crashes, 42 percent reduction in angle crashes and 25 percent reduction in rear-end crashes (Cunningham and Hummer, 2004). Studies in Oxnard, California and Fairfax, Virginia found red light cameras reduced RLR violations by approximately 40 percent (Retting et al., 1999a, Retting et al., 1999b).

2.7.2 Targeted Enforcement

The goal of targeted enforcement is to make the public become more aware of RLR through an increase in ticketed violations or the presence of traffic enforcement agent at an intersection Targeted enforcement is designed to target an identified signalized intersection or corridor where RLR has recently become a problem, or has been identified as a problem through a crash and/or violation study. With this technique, one officer stationed upstream of an intersection will observe the violation, then send a radio message to another officer stationed downstream of the same intersection to pullover the offender and issue a ticket. This technique is regarded as effective in reducing RLR violations however, it is labor-intensive. In some communities, confirmation lights are used as an alternative to team enforcement (Bonneson et al., 2004).

2.7.3 Confirmation Lights

Confirmation lights are a relatively small, low-cost light mounted on the top or the bottom of a traffic signal head or mast arm. This light is sometimes referred to as “Red-Signal Enforcement Lights” or “Red Indication Lights” or “Rat Boxes” or “Tattletale Lights” (Hsu et al., 2009). The confirmation light activates simultaneously during the red signal phase to aid a police officer located downstream of the intersection in observing a RLR violation. After the confirmation light turns on, it is visible 360 degrees from any intersection approach. The confirmation light is wired directly into the red signal aspect and only activates when red light is indicated as shown in Figure 10.

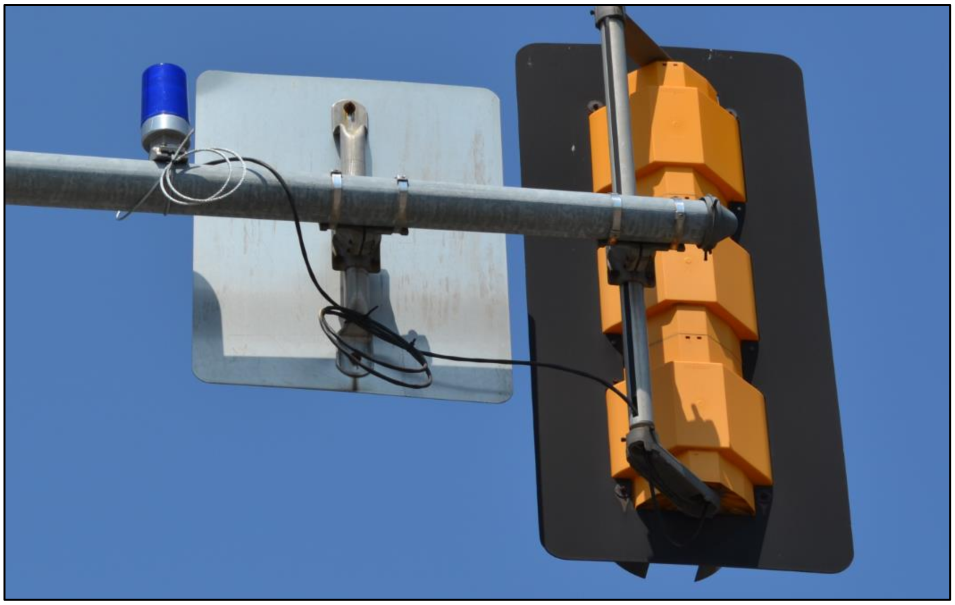

Figure 10. Confirmation light wired directly into red aspect of signal

This system eliminates the need for a team of officers to monitor red light violators at a single intersection, thereby cutting down the police staff to effectively enforce RLR at an intersection. Additionally, the low cost of confirmation lights (cost between $50 and $150 in 2014 dollars) potentially allows more installation at other problematic intersections, hence, increasing enforcement resources efficiently (Hsu et al., 2009).

Reddy et al. (2008) investigated white enforcement lights at 17 intersections on the state highway system in Hillsborough County, Florida. The researchers evaluated effectiveness by a violation and crash analysis. Five months prior to installation, violation data were collected at 24 intersections on weekdays during morning and evening peaks hours. A similar study was conducted in the three months after installation at the 17 intersections in which the lights were installed. Considering all intersections, a total of 759 violations were recorded in the before period while 567 violations were recorded in the after period. It was noted that some intersections saw an increase in violations. A matched-pair t-test was performed and it was determined the reduction in violations were statistically significant. The authors upon further analysis found that the reduction in violations during the morning peak hour were not statistically significant while the evening violations were at the 95 percent level of confidence.

Crash data were obtained from the Florida Department of Transportation for a period of six years (2000-2005). Data from 2000-2002 were considered the before period in which 828 crashes per year occurred at the study intersections of which 56 crashes per year were due to RLR. Data from January 2004 to December 2004 were considered the after period with 2003 being considered the installation period. An average of 860 crashes per year at the study intersections was recorded with 52 crashes per year due to RLR. The authors further broke down the crash analysis and investigated approaches with white enforcement lights and found crashes were reduced from approximately 40 crashes per year to 28 crashes per year.

The Minnesota Local Technical Assistance Program (2009) summarized a completed study conducted by the University of Minnesota and City of Burnsville, Minnesota in which blue confirmation lights were installed at two signalized intersections on County Roads 5 and 11. An investigation assisted by the University of Minnesota saw the daily violation rate reduced by 41 percent. Research also found that violations increased in heavy traffic and most violations occurred during peak hours.

Although confirmation lights have been largely deployed throughout the United States including communities in Florida, Texas, Minnesota, Kentucky and California, limited research studies have been published to determine the effectiveness of the countermeasure in reducing RLR violations or crashes.

2.8 Public Education

Reaching out and educating the public is an effective way to communicate the seriousness of a driver running red light at a signalized intersection. Public education could include media campaigns, grants for targeted enforcement, commercials, further instruction during drivers' education classes, and/or television newscast segments on high crash intersection locations.

2.9 Literature Review Summary

As reported in the literature search, RLR continues to be a serious safety concern and many communities and researchers have investigated countermeasures ranging from low-cost signal timing adjustments to expensive intersection geometric improvements or automated enforcement. To fully address RLR, it takes all aspects of the three Es (Engineering, Enforcement, and Education). As stated previously, this research project is intended to investigate a low-cost countermeasure to aid police officers and make the public aware of RLR at designated intersections in Kansas. This research will provide additional information into the effectiveness of the confirmation light system.

CHAPTER 3: PROBLEM STATEMENT

RLR continues to be a serious safety concern for many communities across the United States. Traditionally, when signalized intersections have been identified as a location with a high number of RLR violations, traditional targeted enforcement is used to reduce the number of violations.

To safely and efficiently enforce RLR at targeted intersections, multiple police officers are needed to verify whether a vehicle ran a red light and to correctly issue a ticket to the offender. Many times, this has required at least one officer watching the signal and stop line while another is waiting downstream of the targeted approach and/or movement. In some instances, an officer observing a RLR violation will chase an offending driver through the intersection, thus exposing him or her to crossing vehicular traffic.

Also stated in the literature search, many communities have turned to automated enforcement to monitor and ticket red light runners at signalized intersections. Automated enforcement, although found by many research studies to be effective at reducing RLR violations and related crashes, have become a target of driver privacy. The State of Kansas currently has legislation that prohibits the use of automated enforcement (State of Kansas, 2013 Statute, 21-6101, subsection (a) (6)), unless deemed essential for safety by a community and all other options have been exhausted. However, automated enforcement can be found in the neighboring state of Missouri.

The objective of this study was to investigate the effectiveness of a low-cost signalized intersection treatment to reduce RLR at signalized intersections. Confirmation lights were chosen as a low-cost option to aid police officers in more easily observing RLR violations when positioned downstream from the intersection. Confirmation lights have been deployed in many communities across the United States. However, limited effectiveness data has been published that can support the effectiveness of this device. Two busy signalized intersections in Lawrence, Kansas were selected as the treatment sites to test the effectiveness of this device.

Effectiveness of the confirmation lights was determined by a before-after violation study. The changes in violations were used as a safety surrogate for the potential changes in crashes. A secondary performance measure that was used included the changes of violation time into red, which is an indicator of how long after the red signal a vehicle violated the red light.

CHAPTER 4: RESEARCH APPROACH

The research study was conducted in Lawrence, Kansas. The City of Lawrence has a population of over 87,000 residents and is the location of the University of Kansas. Kansas Highway 10 (K-10) runs east-west and connects Lawrence to the Kansas City Metropolitan area. Iowa Street (US 59) runs north-south and connects traffic to Interstate 70 (I-70) in the north of Lawrence.

The study intersections were located within city limits, were similar in operation, and had no current or planned construction at the intersection during the study period. Since the project was limited to a 12 month study, a violation study was conducted in place of a crash study which would require multiple years of before and after crash data.

4.1 Measure of Safety

Typical countermeasure effectiveness studies rely on three to six years of before and after crash data (Tarko et al., 2009). However, crash data may be limited due to small sample size and lack of details to explain the mechanisms of crash failures and driver crash avoidance behaviors (Tarko et al., 2009). To measure the safety effect of a treatment, a significant number of crashes need to have been recorded before an action is taken. In situations where a recent countermeasure is implemented such as was the case in this study, it is difficult to measure the safety effect of that countermeasure if crash data from the period prior to and after installation are limited. Because of these issues, other observable non–crash traffic events and surrogate data instead of crash data can be used in road safety analysis. In this research study, before-after violation data were used as a surrogate measure to evaluate the effectiveness of the confirmation light system since crash data were limited.

4.2 Site Selection

Prior to meeting with city officials, 22 intersections were identified as possible sites for installation of the confirmation lights. A set of variables that were investigated at each of the intersections included: approach geometry (e.g. number of lanes, pavement markings, tapers, and right turning lanes), posted speed limited between 30 and 50 mph, protected and/or protected/permitted left turning lanes, a safe location where a police car could be positioned near the intersection approaches, and moderate to high peak hour volumes. Appendix A shows the characteristics and aerial views of the 22 intersections.

The 22 intersections were reduced to 13 candidate sites. This was accomplished by eliminating intersections which did not meet the set of variables explained above. To verify similarities in traffic volumes at specific intersections which were deemed to have the most promise for treatment, nine intersections peak hour traffic counts were collected during the morning and evening peak hours on either a Tuesday, Wednesday, or Thursday between August and September of 2012.

After the manual traffic counts were conducted, it was agreed with the City of Lawrence officials (including the city traffic engineer, traffic signal technician, and the police lieutenant in charge of traffic enforcement), the two treatment sites where the confirmation lights would be installed. Other intersections to be studied to investigate possible spillover effects of the treatment, and control intersections located in different areas of the city were also identified. A total of two treatments sites, six spillover sites, and five control sites were selected as appropriated sites for this study.

4.3 Site Category

4.3.1 Treatment Sites

As stated previously, two signalized intersections in Lawrence were determined to be optimal locations for the confirmation lights to be installed. These included:

- 23rd Street and Iowa Street; and
- 23rd Street and Louisiana Street.

Both of these intersections are located on K-10 which passes through Lawrence. The intersection of 23rd Street and Iowa Street is the highest volume intersection in the city with also the most crashes. Detailed information on each intersection can be found in the following sections. At the request of the Lawrence Police Department, the research team equipped both of these intersections' protected left-turning-movement-only approaches with confirmation lights due to the highest number of red light violations for these movements. Additionally, the intersection of 23rd Street and Iowa Street has a high percentage of heavy vehicles. Heavy vehicles predominantly travel through this intersection by making a left turn from southbound on Iowa Street to eastbound on 23rd Street as a way to access the southern Kansas City Metropolitan area.

4.3.2 Spillover Sites

Spillover sites are signalized intersections located directly adjacent to the two treatment intersections in Lawrence. These included the following locations:

- 19th Street and Iowa Street;
- 19th Street and Louisiana Street;
- 23rd Street and Ousdahl Road;

- 23rd Street and Alabama Street;
- 25th Street and Iowa Street; and
- Clinton Parkway and Crestline Drive.

Previous research relating to automated enforcement has indicated that if an intersection is treated with an enforcement device (e.g. automated red light running camera), similar effects can occur at nearby intersections (Retting and Kyrychenko, 2002, McGee and Eccles, 2003) thus terming the phrase "spillover effect" or "halo effect." It was expected that if a reduction in red light violations occurred at the treatment intersections, a reduction would also be found at these six intersections as well. A map indicating where the treatment and spillover intersections are located is in shown in Figure 11.

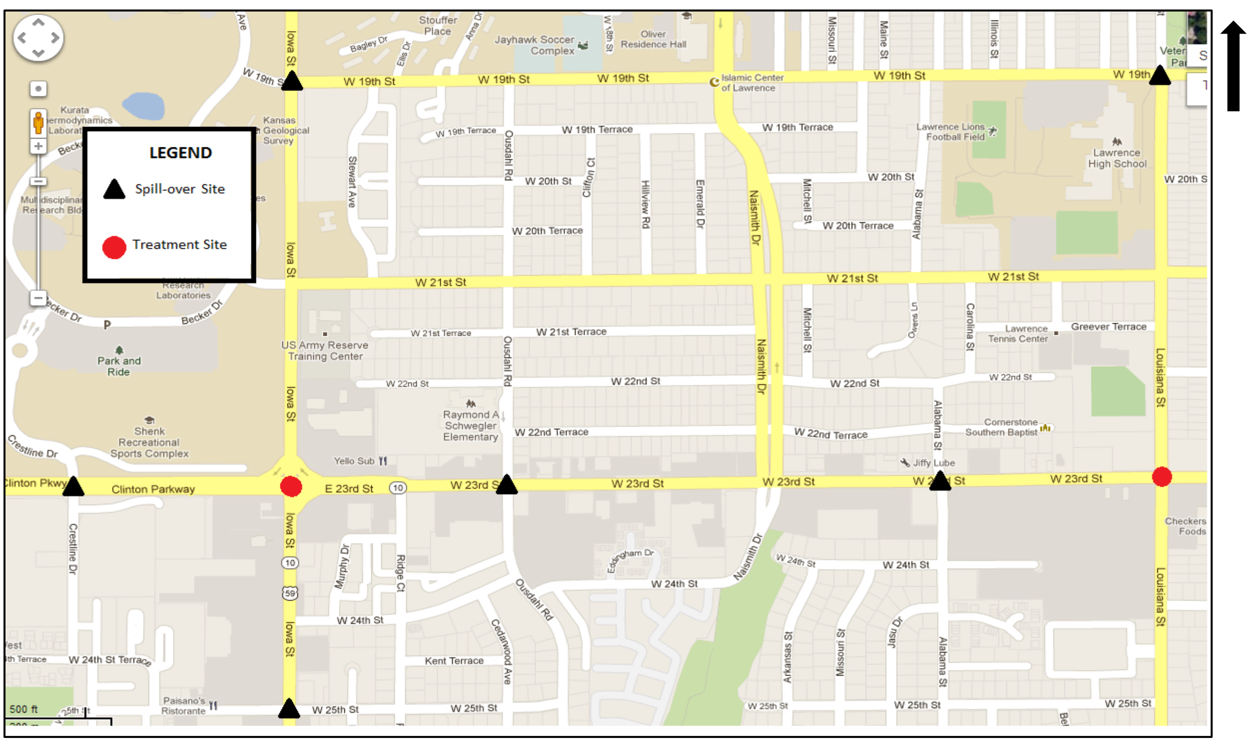

Figure 11. Layout of treatment and spillover intersections in Lawrence, KS (Google maps, 2013)

4.3.3 Control Sites

The five control sites selected for the study were located outside of the study corridor (but still in the limits of Lawrence) and were the following intersections:

- 6th Street and Kasold Drive;
- 6th Street and Michigan Street;
- 6th Street and Wakarusa Drive;
- 31st Street and Iowa Street; and
- Clinton Parkway and Kasold Drive.

The purpose of the control sites were to determine if any changes were happening in Lawrence in terms of red light running. For example, if the research team saw a reduction in red light running violations at both the control and treatment sites, other factors may be contributing to the reduction in red light running that may or may not be quantifiable (e.g. public awareness campaign or targeted enforcement). It was expected that a reduction in violations at the treatment site and a constant or increase in the number of violations at the control site would also be an indicator of treatment effectiveness. Figure 12 shows the location of the treatment sites as well as the control sites.

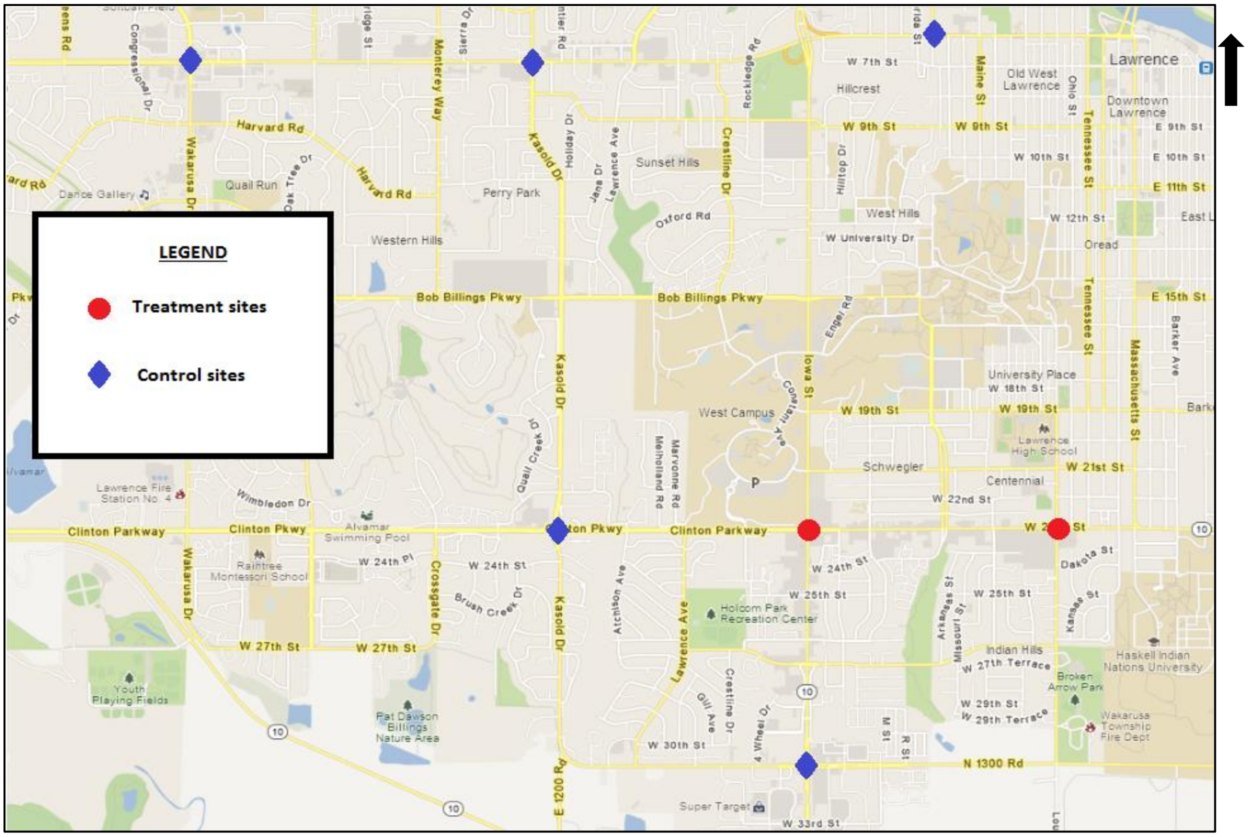

Figure 12. Layout of the control and treatment sites in Lawrence, KS (Google maps, 2013).

4.4 Site Description

As stated in the previous section, 13 intersections were used for this study. This section provides additional information for each intersection. Each intersection has a table that provides posted speed limit, lane configuration (e.g. L = left, T = through, R = right, and shr = shared right turning lane/through lane), number of lanes, and peak hour volumes. The morning and evening peak hours determined by the research team were 7 a.m. to 9 a.m. and 4 p.m. to 6 p.m. on either a Tuesday, Wednesday, or Thursday.

4.4.1 Treatment Sites

4.4.1.1 23rd Street & Iowa Street

Iowa Street (US-59) and 23rd Street (K-10) is located west of downtown Lawrence and south of the University of Kansas. Table 4 provides operational information and the research team noted that this signal operates as a split phase signal timing due to geometric constraints for the southbound and northbound turning movement traffic. As shown in Table 4, right-turning movements were not considered for the northbound, southbound, and westbound movements as they were free right turns as shown in Figure 13.

Table 4. Characteristics of the Intersection of 23rd Street and Iowa Street

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	40			40			45			35		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Number of Lanes	2	2	1	2	2	1	1	2	1	1	2	1
Peak Hour Volumes												
7 a.m. to 9 a.m.	150	960	-[A]	329	526	-[A]	486	1,398	117	209	867	-[A]
4 p.m. to 6 p.m.	243	896	-[A]	493	1,185	-[A]	341	1,212	284	519	1,497	-[A]

[A]Free right-turning movements not included in this study

Figure 13. Aerial view of 23rd Street and Iowa Street (Google maps, 2013)

Figure 14 is a ground view of the intersection looking northbound. As shown, the right-turning movement is a free right with a median island. The northbound and southbound left- turning movements are dual turning lanes and a single protected left-turn signal provides guidance to the vehicles. The two through lanes have a single signal for each lane. A significant number of pedestrians utilize this intersection as a large apartment complex is located south of the intersection. Adjacent to the intersection are commercial developments on three of the four quadrants.

Figure 14. Ground view of the intersection of 23rd Street and Iowa Street (northbound)

4.4.1.2 23rd Street & Louisiana Street

Similar to 23rd Street and Iowa Street, the second treatment site 23rd Street and Louisiana Street is located on the same east-west corridor. This intersection mainly handles east-west traffic as shown in Table 5 by the east and westbound peak hour through movements. During peak hours, a large portion of this traffic consists of commuter traffic to or from the Kansas City Metropolitan area.

Table 5. Characteristics of the Intersection of 23rd Street and Louisiana Street

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	30			30			35			35		
Movement	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Number of Lanes	1	1	1	1	1	1	1	2	shr	1	2	shr
Peak Hour Volumes												
7 a.m. to 9 a.m.	139	414	258	136	244	200	236	1,559	83	133	1,454	199
4 p.m. to 6 p.m.	248	499	357	212	584	243	278	1,823	129	434	1,899	113

Figure 15 shows an aerial view of the intersection and it should be noted that on the northbound and eastbound approaches the gas station driveways are close to the intersection. Commercial development, including a grocery store and strip mall, are located on two of the intersection quadrants.

Figure 15. Aerial view of the intersection of 23rd Street and Louisiana Street (Google maps, 2013)

A ground view of the intersection looking eastbound is shown in Figure 16. As stated previously, the gas station driveways are located close to the intersection. Additionally, northbound and southbound approaches to the intersection operate on a protected and permitted signal. The city had elected to install a single five head “dog house” signal on both approaches. The research team noted this and it is further explained in the following sections as to how this applied to the study.

Figure 16. Ground view of the intersection of 23rd Street and Louisiana Street (eastbound)

4.4.2 Spillover Sites

4.4.2.1 19th Street & Louisiana Street

The intersection of 19th Street and Louisiana Street is located directly north of the intersection of 23rd Street and Louisiana Street. This intersection is one of two spillover intersections for this treatment intersection. This intersection is located between the 23rd Street corridor and the University of Kansas and is adjacent to Lawrence High School. This intersection also handles a significant amount of traffic each day as shown by the eastbound and westbound approaches in Table 6.

Table 6. Characteristics of the Intersection of 23rd Street and Louisiana Street

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	30			30			30			30		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Number of lanes	1	1	1	1	1	shr	1	1	1	1	1	shr
Peak Hour Volumes												
7 a.m. to 9 a.m.	323	86	293	24	46	31	13	553	148	285	833	23
4 p.m. to 6 p.m.	139	447	100	87	153	21	26	806	206	542	1,001	17

As shown by the aerial image in Figure 17, the intersection is located in a residential area with Lawrence High School located in the southwest Quadrant. A city park is located on the northeast quadrant and single family homes and business driveways are located near the intersection in the other two quadrants.

Figure 17. Aerial view of the intersection of 19th Street and Louisiana Street (Google maps, 2013)

Shown in Figure 18 is a ground view of the intersection looking eastbound. As shown, left-turns for all approaches are protected/permitted using a four signal head unit that is vertical. Additionally, right-turns for all approaches are controlled by a permitted/protected signal as well. Through movements are controlled by a single signal over the lane for all approaches.

Figure 18. Ground view of the intersection of 19th Street and Louisiana Street (eastbound)

4.4.2.2 23rd Street & Alabama Street

Moving down the corridor west to east, the intersection of 23rd Street and Alabama Street is the first spillover intersection located near the intersection of 23rd Street & Louisiana Street. As shown in Table 7, this intersection handles a similar amount of eastbound and westbound commuter traffic. The northbound and southbound approaches are considered minor roadways.

Table 7. Characteristics of the Intersection of 23rd Street and Alabama Street

Approach	**Northbound**			**Southbound**			**Eastbound**			**Westbound**		
Posted Speed Limit	**30**			**30**			**35**			**35**		
Movement	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Number of Lanes	1	1	shr	1	1	Shr	1	2	shr	1	2	shr
Peak Hour Volumes												
7 a.m. to 9 a.m.	112	84	176	18	29	29	59	1,637	63	49	1,570	14
4 p.m. to 6 p.m.	177	62	113	62	98	62	78	2,299	159	147	2,404	51

As shown in Figure 19, this intersection has car dealerships on two of the quadrants and a fast food restaurant on the northeast quadrant. Each eastbound and westbound left-turning lane is an extension on the two-way-left-turning-lane (TWLTL).

Figure 19. Aerial view of the intersection of 23rd Street and Alabama Street (Google maps, 2013)

Figure 20 is a ground view of the intersection looking westbound. As shown, the eastbound and westbound left-turning movement signal is the same “dog house” configuration with five signal heads, one on top and two on each side. The northbound and southbound movement is controlled by a single signal head. Also shown in this Figure is an excellent view of the 23rd Street corridor, note the continued TWLTL. Finally, this intersection flashes yellow in the eastbound and westbound directions after 11 p.m.

Figure 20. Ground view of the intersection of 23rd Street and Alabama Street (westbound)

4.4.2.3 23rd Street and Ousdahl Road

The intersection of 23rd Street and Ousdahl Road is the east spillover intersection for the treatment intersection of 23rd Street and Iowa Street. Similar to the previously mentioned spillover intersection, this signalized intersection also handles a significant number of eastbound and westbound traffic along 23rd Street. The northbound and southbound approaches are minor roads and have shared lanes as shown in Table 8.

Table 8. Characteristics of the Intersection of 23rd Street and Ousdahl Road

Approach		**Northbound**			**Southbound**			**Eastbound**			**Westbound**	
Posted Speed Limit		**30**			**30**			**35**			**35**	
Movement	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Number of Lanes	shr	1	shr	shr	1	shr	1	2	shr	1	2	shr
Peak Hour Volumes												
7 a.m. to 9 a.m.	34	69	30	56	161	71	246	1,878	37	42	1,552	68
4 p.m. to 6 p.m.	123	91	78	84	145	187	136	2,124	95	102	2,107	93

As shown in Figure 21, near the intersection are multiple restaurants and on the south-west side of the intersection is the large parking lot of a Hobby Lobby. A residential area including single family homes and apartment complexes are both north and south of the intersection.

Figure 21. Aerial view of the intersection of 23rd Street and Ousdahl Road (Google maps, 2013)

Shown in Figure 22 is a ground view of the intersection looking east. Similar to the previously mentioned spillover intersections, eastbound and westbound approach left-turns are controlled by protected/permitted “dog house” signals. Northbound and southbound turning movements are controlled by a single signal head. Also shown in Figure 22 is a pedestrian crossing sign, since an elementary school is located north of the intersection and there are children crossing the intersection during the a.m. peak hour times.

Figure 22. Ground view of the intersection of 23rd Street and Ousdahl Road (eastbound)

4.4.2.4 Clinton Parkway & Crestline Drive

The intersection of Clinton Parkway (23rd Street) and Crestline Drive is the spillover intersection located directly west of the 23rd Street and Iowa Street intersection. Similar to the previously mentioned spillover intersections, this signalized intersection also handles a significant amount of eastbound and westbound traffic. However, this intersection is the entrance to the University of Kansas commuter' parking lot. This is reflected in the morning northbound left and right, and evening left and right movements as shown in Table 9.

Table 9. Characteristics of the Intersection of Clinton Parkway and Crestline Drive

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	30			20			45			45		
Movement	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Number of Lanes	1	1	1	1	1	shr	1	2	1	1	2	1
Peak Hour Volumes												
7 a.m. to 9 a.m.	107	18	172	8	4	33	279	2,098	239	122	1,196	142
4 p.m. to 6 p.m.	142	6	56	163	12	204	53	1,800	116	59	1,659	31

Figure 23 shows an aerial view of the intersection with the entrance to the University of Kansas commuter parking lot on the north side. The eastbound and westbound approaches have a raised center median and a separate right-turning lane for all approaches.

Figure 23. Aerial view of the intersection of Clinton Parkway and Crestline Drive (Google maps, 2013)

Figure 24 is a ground view of the intersection looking westbound. As shown, all of the approaches' left-turning movements are permitted/protected by "dog house" signal configurations. Additionally, a permitted right-turn signal is present to help control right-turning movement for the northbound and westbound approaches.

Figure 24. Ground view of the intersection of Clinton Parkway and Crestline Drive (westbound)

4.4.2.5 19^{th} Street & Iowa Street

The intersection of 19^{th} Street and Iowa Street is located directly north of the intersection of 23^{rd} Street and Iowa Street. As shown in Table 10, this intersection handles a lot of north and southbound traffic. This traffic is made up of commuters to the University of Kansas campus and also traffic that has exited I-70 in north Lawrence and are wanting to turn left at the intersection of 23^{rd} Street and Iowa Street to take K-10 to the south Kansas City Metropolitan area.

Table 10. Characteristics of the Intersection of 19th Street and Iowa Street

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	40			40			30			30		
Movement	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Number of Lanes	1	2	shr	1	2	1	1	1	shr	1	1	1
Peak Hour Volumes												
7 a.m. to 9 a.m.	32	1,655	386	478	1,325	112	15	133	30	186	108	484
4 p.m. to 6 p.m.	71	1,894	313	475	2,352	28	73	160	129	513	109	548

Figure 25 is an aerial view of the intersection. The University of Kansas campus is located on three of the four quadrants with an apartment complex and fire station located on the southeast quadrant. The northbound and southbound left-turning lanes are offset with a painted median. The intersection is on a grade with the crest of the hill located north of the intersection.

Figure 25. Aerial view of the intersection of 19th Street and Iowa Street (Google maps, 2013)

Shown in Figure 26 is the intersection during the evening peak hour looking northbound. This figure also gives an excellent view of the uphill grade. There is a signal over each of the four through movement approaches and a single protected signal for the northbound and southbound left-turning movements. Eastbound and westbound (minor streets) left-turning movements are controlled by a protected/permitted signal.

Figure 26. Ground view of the intersection of 19th Street and Iowa Street (northbound)

4.4.2.6 25th Street & Iowa Street

The intersection of 25th Street and Iowa Street is located directly south of the intersection of 23rd Street and Iowa Street. As shown by Table 11, most of the traffic during the peak hours is northbound and southbound with the minor streets being eastbound and westbound.

Table 11. Characteristics of the Intersection of 25th Street and Iowa Street

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted speed limit	40			40			30			30		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Number of lanes	1	2	shr	1	2	shr	shr	1	shr	shr	1	shr
Peak Hour Volumes												
7 a.m. to 9 a.m.	34	1,467	24	24	762	65	85	32	36	20	17	37
4 p.m. to 6 p.m.	82	2,136	44	67	1,984	98	147	46	53	94	68	49

This intersection as shown in Figure 27 is surrounded by commercial developments including restaurants and gas stations. The northbound and southbound left-turning lane is offset with a painted median.

Figure 27. Aerial view of the intersection of 25th Street and Iowa Street (Google maps, 2013)

Figure 28 shows a ground view of the intersection facing northbound. As shown, vehicles traveling northbound are cresting a vertical curve before they approach the intersection of 23rd Street and Iowa Street. There is a single signal for each northbound and southbound through movement and a single signal for all movements eastbound and westbound. The northbound and southbound left-turning movements are permitted/protected and, similar to other spillover intersections, are a “dog house” signal configuration.

Figure 28. Ground view of the intersection of 25th Street & Iowa Street (northbound)

4.4.3 Control Sites

4.4.3.1 6th Street & Kasold Drive

The intersection of 6th Street (US-40) and Kasold Drive is a large signalized intersection in northwest Lawrence. The intersection is fully actuated and handles a significant amount of east-west traffic (shown in Table 12) as 6th Street is one route commuters take to and from Topeka, Kansas.

Table 12. Characteristics of the Intersection of 6th Street and Kasold Drive

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	30			30			35			35		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Number of lanes	1	1	1	1	2	shr	2	2	1	2	2	1
Peak Hour Volumes												
7 a.m. to 9 a.m.	232	186	337	218	336	93	39	1,579	229	200	1,026	58
4 p.m. to 6 p.m.	495	358	349	174	361	120	118	1,609	346	420	1,955	139

Figure 29 is an aerial view of the intersection. As shown, the eastbound and westbound approaches have two protected left-turning lanes and the northbound and southbound approaches have one left-turning lane that is permitted/protected. Surrounding the intersection is a gas station (northwest quadrant) and Walgreens (southeast quadrant) where driveway access is close to the intersection. Additionally, a strip mall and bank are in the other two quadrants of the intersection.

Figure 29. Aerial view of the intersection of 6th Street and Kasold Drive (Google maps, 2013).

A ground view of the intersection facing eastbound is shown in Figure 30. As shown, a raised six inch median stretches along the length of the eastbound and westbound left-turning lanes. Additionally, the eastbound approach has a right-turning lane that also serves as a bus stop.

Figure 30. Ground view of the intersection of 6th Street and Kasold Drive (eastbound)

4.4.3.2 6th Street & Wakarusa Drive

Continuing west on 6th Street and also located in the northwest part of Lawrence is the intersection of 6th Street (US-40) and Wakarusa Drive. This intersection also handles significant east-west commuter traffic as well as southbound and northbound high school and residential traffic. The operational data collected in the field is shown in Table 13.

Table 13. Characteristics of the Intersection of 6th Street and Wakarusa Drive

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	45			45			45			45		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Number of lanes	2	2	1	2	2	1	2	2	1	2	2	1
Peak Hour Volumes												
7 a.m. to 9 a.m.	325	260	404	145	235	63	46	643	214	493	552	66
4 p.m. to 6 p.m.	318	316	627	227	311	66	56	868	235	633	752	206

An aerial view of the intersection is shown in Figure 31. As shown, all approaches have two protected left-turning lanes. All approaches besides the northbound approach have permitted right-turning lanes.

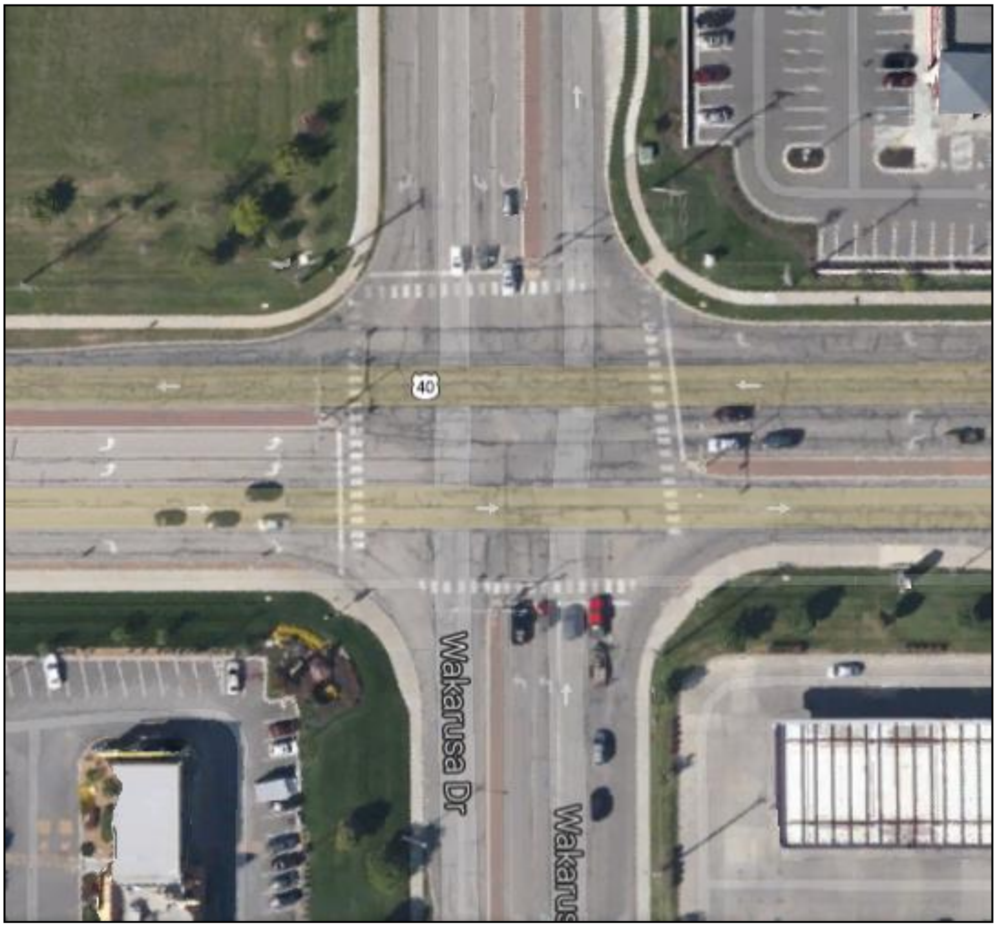

Figure 31. Aerial view of the intersection of 6th Street and Wakatrusa Drive (Google maps, 2013)

Figure 32 shows a ground view of the intersection facing eastbound. As shown, each approach has a raised median with the traffic signal pole and mast arm located in the center of the intersection. Also note that there are two protected left-turning signals with one of the signals directly over the lane and one lower at the center of the pole. The intersection is surrounded by commercial development with driveway access far from where the intersection queue would occur.

Figure 32. Ground view of the intersection of 6th Street and Wakarusa Drive (eastbound)

4.4.3.3 6th Street and Michigan Street.

The intersection of 6th Street (US-40) and Michigan Street is close to downtown Lawrence. The intersection serves a considerable amount of east-west traffic similar to the other two control intersections along 6th Street. Additionally, the intersection serves the Lawrence hospital and residential areas in north Lawrence. This intersection flashes yellow after 11 p.m. similar to other minor intersections in the city. Table 14 shows the characteristics of this intersection.

Table 14. Characteristics of the Intersection of 6th Street and Michigan Street

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	30			20			35			35		
Movement	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Number of lanes	shr	1	shr	shr	1	shr	1	2	shr	1	2	shr
Peak Hour Volumes												
7 a.m. to 9 a.m.	68	78	18	411	71	86	65	1,733	32	13	1,348	216
4 p.m. to 6 p.m.	123	101	20	403	65	215	69	1,841	53	19	2,243	220

Figure 33 shows an aerial view of the intersection. As shown, the left-turning lanes are part of a TWLTL through this part of 6th Street. The westbound approach has a permitted right- turning lane. The photo was taken in 2011 when a new overlay and pavement markings were installed. This intersection also has pedestrian traffic as this is one way for residents to travel from the north Lawrence housing developments to the University of Kansas.

Figure 33. Aerial view of the intersection of 6th Street and Michigan Street (Google maps, 2013)

Figure 34 is a ground view of the intersection facing eastbound. As shown, all approaches have permitted signals for the through, right, and left-turning movements. Surrounding the intersection are restaurants and small businesses. A business with driveway access very close to the intersection is a Dunkin Donuts, which is located in the intersection's northwest quadrant as shown in Figure 33.

Figure 34. Ground view of the intersection of 6^{th} Street and Michigan Street (eastbound)

4.4.3.4 *31st Street & Iowa Street*

The intersection of 31st Street and Iowa Street is located at the south end of Lawrence. This intersection handles a considerable amount of north-south traffic of commuters traveling to Lawrence from the south and also traffic that has taken the K-10 bypass around west Lawrence. Table 15 shows the peak hour volumes for the intersection. East-west traffic is local traffic and those wishing to access large commercial developments surrounding the intersection.

Table 15. Characteristics of the Intersection of 31st Street and Iowa Street

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	45			45			40			40		
Movement	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Number of lanes	2	2	1	2	2	1	2	2	1	2	2	1
Peak Hour Volumes												
7 a.m. to 9 a.m.	95	916	220	115	442	171	206	402	108	138	300	208
4 p.m. to 6 p.m.	251	923	187	376	1,092	358	395	514	253	249	488	261

An aerial view of the intersection is shown in Figure 35. The intersection is fully actuated and has dual protected left-turning lanes for all approaches and permitted right-turning lanes for all approaches. The intersection is surrounded by banks and strip malls including a discount superstore.

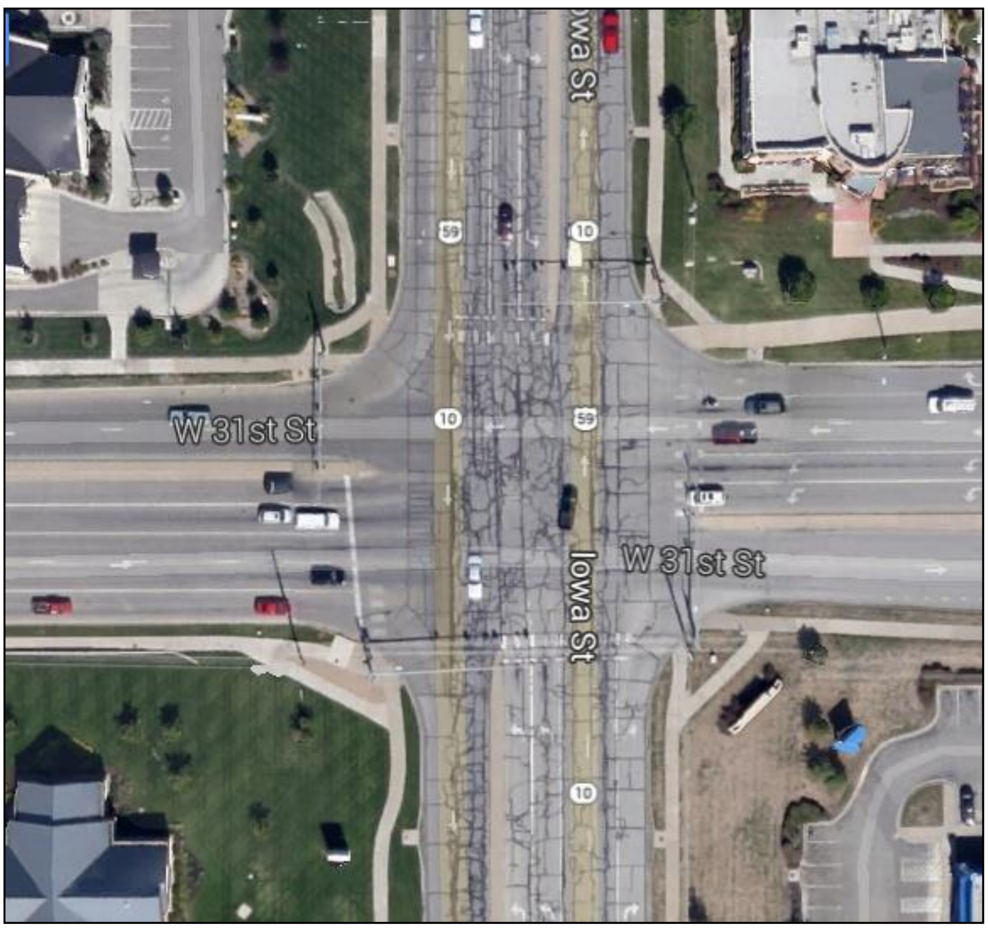

Figure 35. Aerial view of the intersection of 31st Street and Iowa Street (Google maps, 2013)

A ground view of the intersection is shown in Figure 36 facing northbound. As shown, each lane has a signal head over it. Additionally, a raised median is located on all approaches. Driveway accesses to the adjacent properties are signal controlled and are not close to the intersection.

Figure 36. Ground view of the intersection of 31st Street and Iowa Street (northbound)

4.4.3.5 Clinton Parkway & Kasold Drive

The intersection of Clinton Parkway and Kasold Drive is a large signalized intersection located southwest of downtown Lawrence. This intersection handles a significant amount of commuter traffic traveling east and west in the south part of the city as shown in Table 16.

Table 16. Characteristics of the Intersection of Clinton Parkway and Kasold Drive

Approach	Northbound			Southbound			Eastbound			Westbound		
Posted Speed Limit	40			40			45			45		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Number of lanes	1	2	1	1	2	shr	1	2	1	1	2	1
Peak Hour Volumes												
7 a.m. to 9 a.m.	146	371	197	428	315	98	169	1,394	185	125	791	355
4 p.m. to 6 p.m.	275	606	201	582	643	223	137	1,118	301	262	1,465	643

An aerial image of the intersection shown in Figure 37 shows three of the four approaches having raised medians with the northbound approach having a painted median. Pedestrian traffic is mainly east-west with a public drinking fountain located on the sidewalk in the southeast quadrant. Surrounding the intersection are a strip mall with a grocery store, residential areas, and a medical complex.

Figure 37. Aerial view of the intersection of Clinton Parkway and Kasold Drive (Google maps, 2013)

A ground view of the intersection is shown in Figure 38. Eastbound and westbound left-turning movements are protected while the southbound and northbound left-turning movements are protected/permitted using the “dog house” type signal. The eastbound and westbound approaches also have a permitted right-turning signal for the right-turning movement.

Figure 38. Ground view of the intersection of Clinton Parkway and Kasold Drive (westbound)

4.5 Field Data Collection

As stated previously, a before-after violation study was conducted to determine the effectiveness of the blue confirmation lights at two signalized intersections in Lawrence. The best way to collect violation data was by using video cameras. However, collecting and reducing video data was complicated and time consuming. The initial idea was to use the permanently installed pan/tilt/zoom cameras located at the all of the intersections to record the video, however, the field of view did not allow for sufficient data extraction. One field of view that could monitor a single approach was needed to collect and reduce the data as shown in Figure 39.

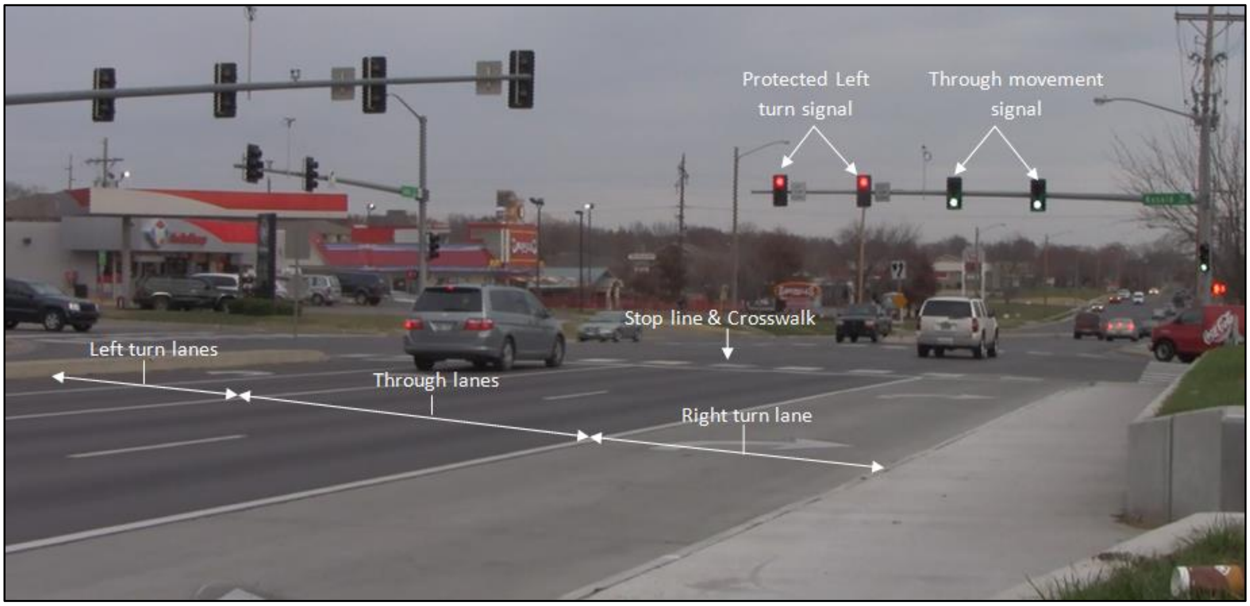

Figure 39. Camera view of an intersection approach

As stated in the previous section, almost all of the intersections under investigation had multiple lanes and sometimes a right-turning lane. The field of view also needed to include the stop bar and traffic signals. As shown in Figure 39, this field of view was for the eastbound approach at the intersection of 6th Street and Kasold Drive.

Commonly available equipment were used for the data collection effort. The high definition video cameras used to collect the data had a maximum battery life of 0.5 to 1 hour, thus needing either an extended battery pack, or a deep cell battery and inverter were used to extend the record time of each camera as shown in Figure 40.

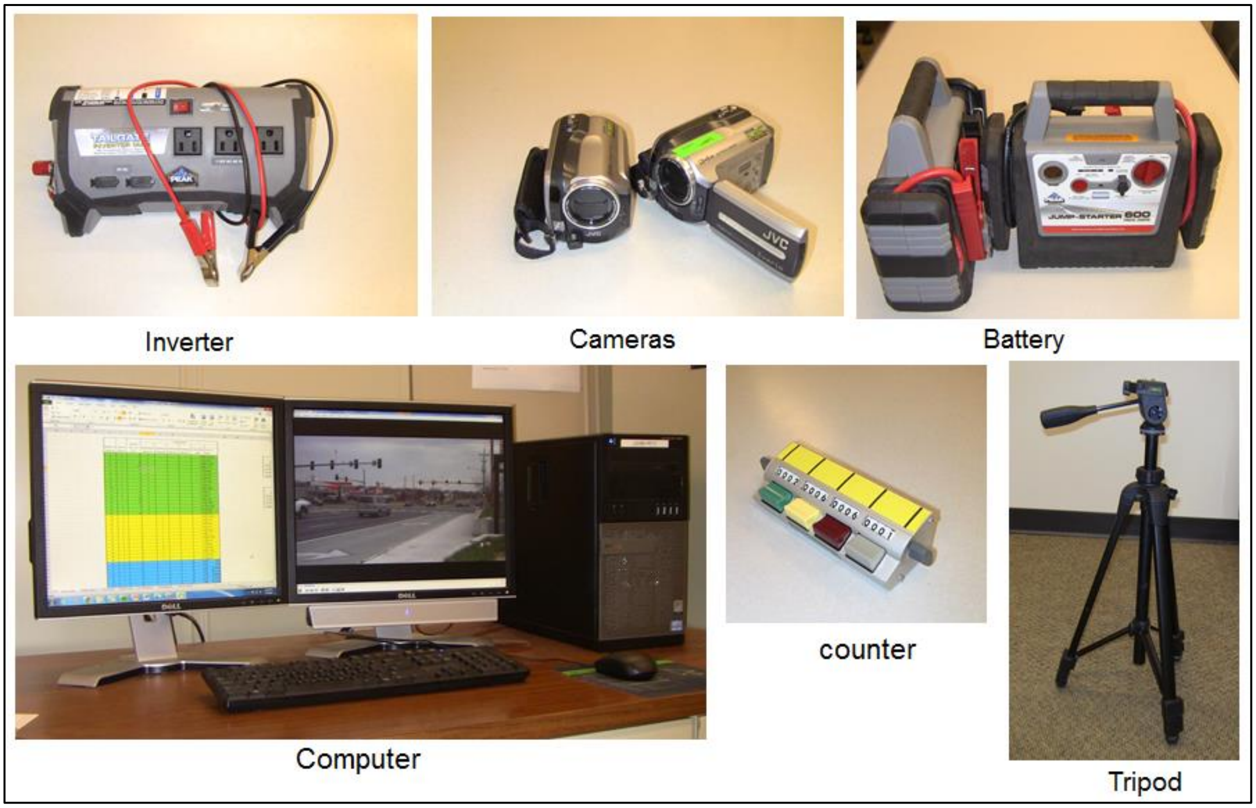

Figure 40. Equipment used for field data collection effort

Another important aspect to the data collection methodology was setting up the video camera equipment at all four approaches of each intersection as shown in Figure 41. Each camera set-up was positioned as far from the traveled lanes as practicable to minimize the likelihood of drivers noticing it. The camera set-ups were monitored from a vehicle parked close by. Figure 42 shows an example of the set-up of the equipment at the eastbound approach of the intersection of 23rd Street and Louisiana Street. Prior to video data collection at any intersection, a notice was given the City of Lawrence Police Department dispatch team.

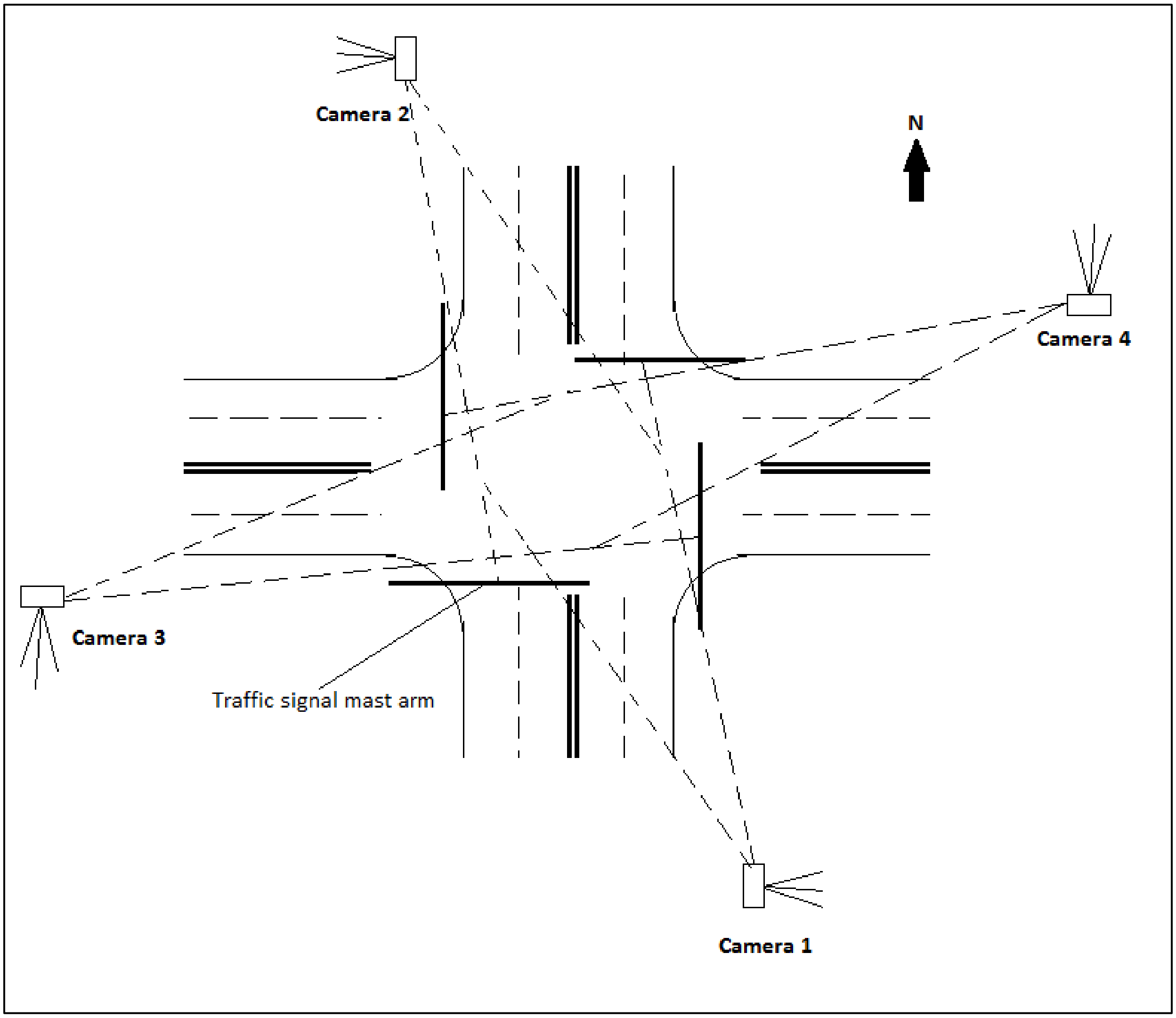

Figure 41. Camera positions at intersection

Figure 42. Setting-up of a camera to record RLR violations.

Video data were collected on weekdays that were non-holidays or during a special event (e.g. basketball game) on either a Tuesday, Wednesday, or Thursday. Data were collected during the morning peak hour (7 a.m. to 9 a.m.) and evening peak hour (4 p.m. to 6 p.m.). A similar data collection methodology was used for the after study. The dates in which video data were collected including the installation date are as follows:

- Before study – October 17 to November 29, 2012;
- Confirmation Light Installation – July 1 to July 2, 2013;
- One month after study – August 6 to August 22, 2013; and
- Three month after study – October 9 to November 5, 2013.

As shown by these data collection dates, videotaping intersections twice on a single day took a considerable amount of staff time with limited equipment. Quality control in the field was imperative to obtain accurate results.

4.6 Data Reduction

A total of 760 hours of video data were collected for the entire project which resulted in over 2 terabytes of high definition video. Intersection video data were reduced manually by student undergraduate research assistants. A methodology was developed to ensure accurate video data reduction. Students reduced the peak hour data at all previously listed intersections. The following guidelines were given to each student to reduce the video data:

- A vehicle that proceeded through (or crossed the stop bar), made a right-turn or made a left-turn after the red signal was shown was considered a RLR violation.
- A vehicle that crossed the stop bar during the yellow interval, or was in the intersection when the signal showed yellow or red was not considered a RLR violation (e.g. permitted left-turns).
- A vehicle that made a right-turn on red without coming to a complete stop was considered a RLR violation.
- If a vehicle ran a red light, calculate the time into red and record.
- If a vehicle ran a red light, record by indicating the type of vehicle (e.g. passenger car (1), truck (2), bus (3) or recreational vehicle (4)).
- While monitoring one approach at a time for RLR violations, the traffic counts for each lane were recorded.
- Violations were recorded based on the configurations shown in Figure 43. Table 17 explains the configurations indicated by codes (0 through 9) in Figure 43.

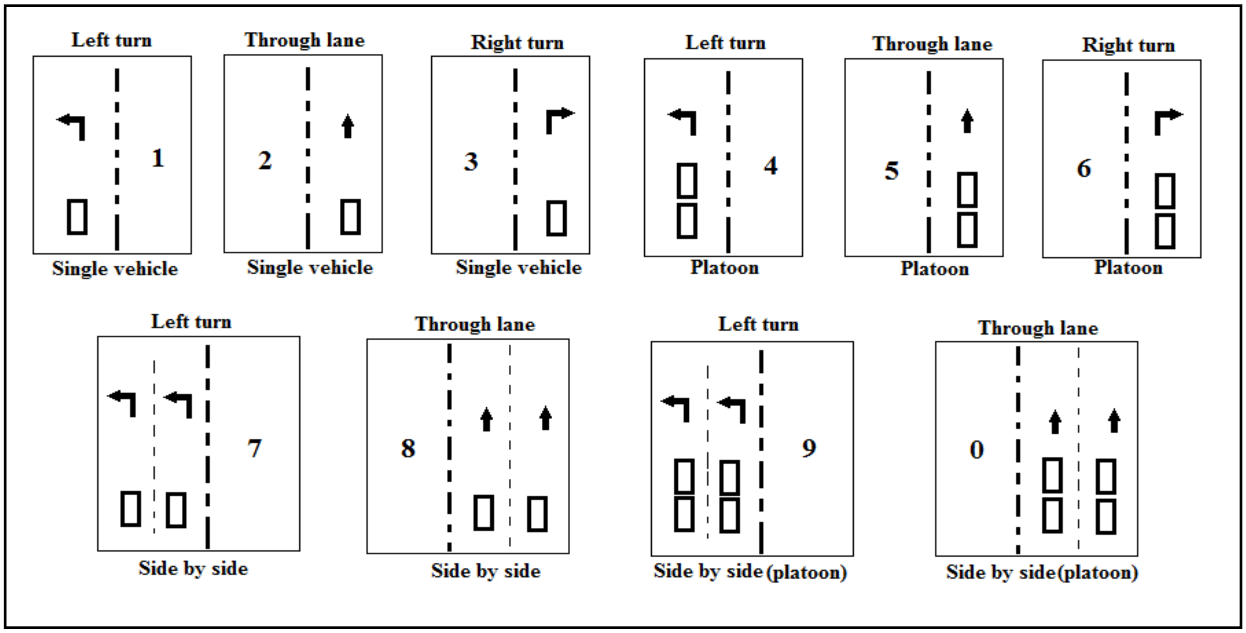

Figure 43. RLR violation configurations

Table 17. RLR Violation Configuration Description

Code	Violation Description
0	Three or more vehicles following closely (in platoon) violate red light together traveling side by side (double through lane)
1	A single vehicle violates red light when making a left turn
2	A single vehicle violates red light when it proceeds through intersection
3	A single vehicle violates red light when making a right turn
4	Two or more vehicles in platoon violate the red light when making left turn
5	Two or more vehicles in platoon violate the red light when they proceed through intersection
6	Two or more vehicles in platoon violate the red light when making right turn
7	Two vehicles violate red light together traveling side by side (double left turn)
8	Two vehicles violate red light together traveling sided be side (double through lane)
9	Three or more vehicles in platoon violate red light together traveling side by side (double left turn)

Illustrated in Figure 44 is the template that was distributed to the students that reduced the video data.

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m./p.m.)
1	2	2		1			7:35 a.m.
2	1	6	3				4:15 p.m.
3	3	2				7	8:20 a.m.
4	1	2				7	5:50 p.m.
5	4	1			2		
6							

Approach	Morning or Evening Peak Volume			
	Left turn	Through	Right turn	Total Volume
NB	55	7	61	**123**
SB	6	3	13	**22**
EB	24	951	18	**993**
WB	140	1579	75	**1794**

Figure 44. Sample of reduced data in Microsoft Excel sheet

The primary data of interest shown in Figure 44 are the number of vehicle that ran the red light, type of vehicle, seconds into red, on which approach the violation occurred, the type of configuration, and the time of day the violation occurred. Additionally, the turning movement counts are shown for each approach. Detailed results for all the study intersections are shown in Appendix B.

Once a student completed an intersection (including all four approaches), the sheet was given to one person to perform a quality check/assurance. Any recorded incident as a violation was reviewed to ensure a RLR violation occurred and was recorded accurately. Once the data reduction effort was complete, the data were aggregated into one excel file for analysis.

4.7 Data Collection and Reduction Limitations

Collecting field data can result in unknown and sometimes complicating situations. Some of the challenges which complicated the data collection and reduction efforts included the following:

- A RLR crash was observed at one of the treatment sites (23rd Street and Iowa Street) during the 3 months after data collection during the morning peak hour. Prior to this crash, video data were only collected for an hour. Due to the intersection being shut down temporarily by the Lawrence Police Department, video data were recollected on a different week day.
- At the intersection of 6th Street and Kasold Drive, the video camera monitoring the eastbound approach was stolen. The data stored on the camera were lost and data were collected at the intersection the following day.
- After 45 minutes of data collection at the intersection of 23rd Street and Louisiana Street during the 3 months period, a contractor entered the intersection to setup a temporary work zone, delaying the data collection effort for another weekday.
- During the data collection effort, Kansas weather brought rain, wind, sleet, and snow. In those circumstances, the set-ups were either shut down early, or readjusted (e.g. using plastic bags to cover cameras or chain the set-ups tied down).
- Since the research project utilized commonly available video recording and power source equipment, limitations on equipment reliability was an issue during some recording sessions. This included malfunctioning batteries, inverters, or cameras. Identified equipment failure was noted either in the field or during the data reduction process and data recollection occurred as quickly as possible.
- At many locations, pedestrian's passing by the camera setups began to tamper with the units. Once they see someone monitoring the set-ups, they left the area. Camera equipment was checked immediately every time this happened.

4.8 Installation of Confirmation Lights

Pelco confirmation lights, which range from $110-$140 depending on the mounting bracket were installed at the two treatment sites. As shown in Figure 10, the City of Lawrence specified that the light be mounted by a cable Astro-Brac. Also shown in Figure 10, excess cable and wire were zip-chord strapped to the mast arm and sign bracket. The Pelco confirmation light comes in multiple colors including blue, red, and clear. A standard Edison light bulb is used and the plastic dome is sealed by a rubber weather stripping. The confirmation comes with a short three strand wire which included a ground wire. The Lawrence traffic signal technicians removed the provided wire and attached a standard two-wire.

Since the traffic signal controller cabinet and signal heads were low-powered LEDs, the city requested for the brightest low-powered light bulb because a conventional 65 watt incandescent bulbs would trip the intersection battery backup system. Three LED light bulbs and an 800 Lumens 9 Watt LED light bulb were selected for installation.

The confirmation lights were installed on left-turn signals at both intersections (23rd Street and Iowa Street & 23rd Street and Louisiana Street) on July 2, 2013, between 9 a.m. and 10 a.m. At the intersection of 23rd and Louisiana, the lights were installed only on the eastbound and westbound approaches. The northbound and southbound approaches had protected-permitted left- turn signals which makes the confirmations lights not to work as expected. The permitted phase for left-turning movements will show both solid red and solid green indications and at the same time, activates the confirmation lights. In such instance, it will be confusing for a police officer located downstream of an intersection to tell whether a violation occurred during the permitted phase or after the red signal indication. In order to avoid such confusion, the confirmation lights were installed on protected left-turn approaches only. Figure 45 shows a field installation of the confirmation lights by the City of Lawrence at the Intersection of 23rd Street and Iowa Street.

Figure 45. Field installation of the confirmation light

4.9 Public Awareness of the Confirmation Lights

Prior to installation and activation of the blue confirmation lights at both intersections, the City of Lawrence consulted with the city and country traffic judges as well as the city and county prosecutors so unintentional confusing would not happen if the court system saw the words “blue light” on a citation.

Additionally, the University of Kansas and the City of Lawrence jointly released a statement regarding the project. Copies of the press releases can be found in Appendix C. The coordinated press releases were designed to inform drivers that a change was happening at two intersections and a different color was going to be present besides red, yellow and green. The press releases were also designed to show commitments to intersection safety by the City. Shown in Figures 46 and 47 are the blue confirmations lights during the daytime and nighttime, respectively, at the intersection of 23th Street and Louisiana Street.

Figure 46. Daytime operation at 23rd Street and Louisiana Street

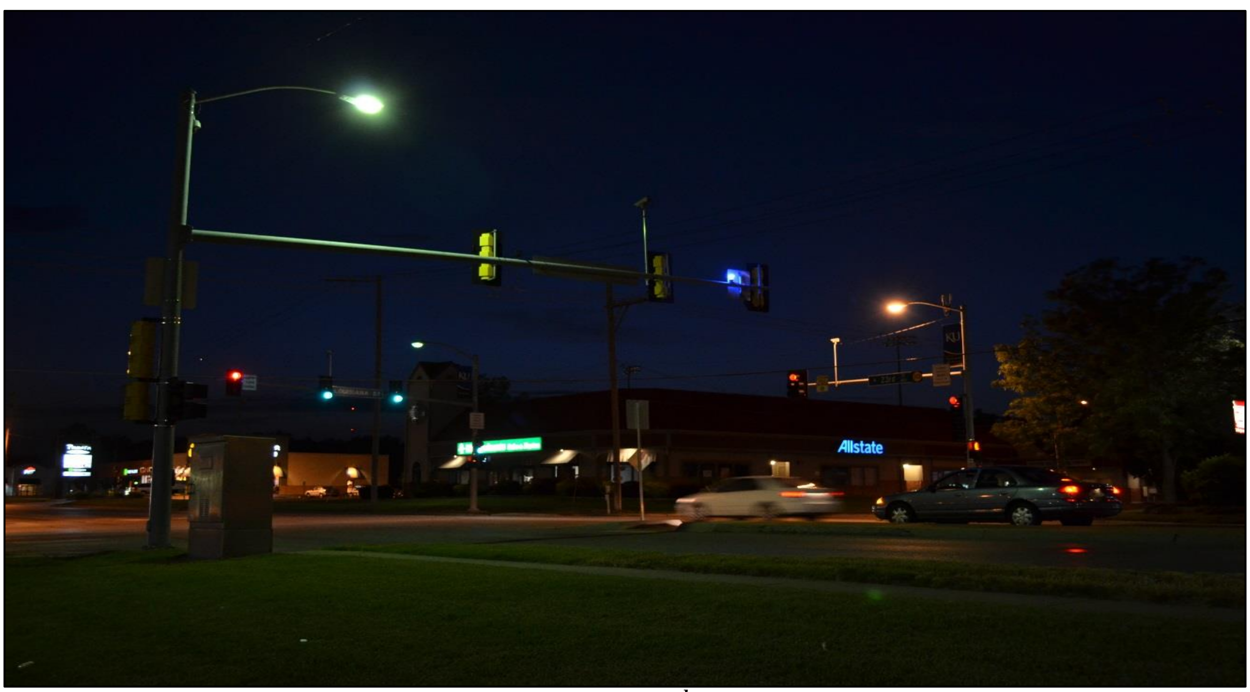

Figure 47. Nighttime operation at 23rd Street and Louisiana Street

Additionally, the research project was spotlighted by local television and newspaper media. A photo of the principal investigator answering questions by the local media is shown in Figure 48.

Figure 48. Project investigator meeting with the media at one of the treatment intersections

It should be noted that the effectiveness of the public awareness campaign was not evaluated as part of this study. Additionally, the Lawrence Police Department continued their regular duties monitoring RLR to avoid targeted enforcement during the study period.

CHAPTER 5: RESULTS

This chapter presents the descriptive statistics of all the before and after RLR violation data collected at the 13 study intersections. Variables including: RLR violation rates by intersection lane, time of the day when RLR violations occurred, time into red, the vehicle types involved in RLR violations, and the RLR violations by configuration type, are presented in this chapter.

5.1. RLR Violation Rates by Intersection Lane

5.1.1 Background

The severity of RLR crashes depends on typical signalized intersection crash types such as right-angle, rear end, left turn and/or sideswipe. Right-angle crashes have more serious safety implications than other crash types. Since signalized intersection crash type largely depends on vehicle movement at a signalized intersection, the violation rates by lane were investigated to determine how serious RLR violations are for each of the three possible movements: left turn, right turn, and through.

5.1.2 Methodology

Data were reduced as described in Chapter 4. RLR violations were expressed as a rate (violations per 10,000 entering vehicles) by using Equation 3.

$$\boldsymbol{Rate(TEV) = \frac{N_i}{V_i} \times 10,000\ Entering\ Vehicle} \qquad \textbf{Eq. 3}$$

Where: N_i = total number of violations (N) observed during the study period i

V_i = total number of entering vehicles (V) during the study period i

A rate was used to account for varying intersection traffic volumes (exposure). The morning peak hour violations as well as the evening peak hour violations for each study site were combined. Then, the violation rates were plotted on the y-axis and the site categories on the x-axis for all the study periods. The next section provides detail results for the morning and evening peak hours' violations.

5.1.3 Results

5.1.3.1 Left-turn RLR Violation Rates

Figure 49 shows the left-turn RLR violation rates for the three types of study sites during the morning peak hours. As shown, the treatment site saw the highest violation rates during the before, one month and three months after installation of the confirmation lights. The treatment and spillover sites saw greater reductions in the violation rate one month after the installation than the control sites. Additionally, these sites saw further decreases in violation rates three months after the installation. At the control sites, violation rates decreased during the one month after study but remained the same as the before violation rate during the three months after study.

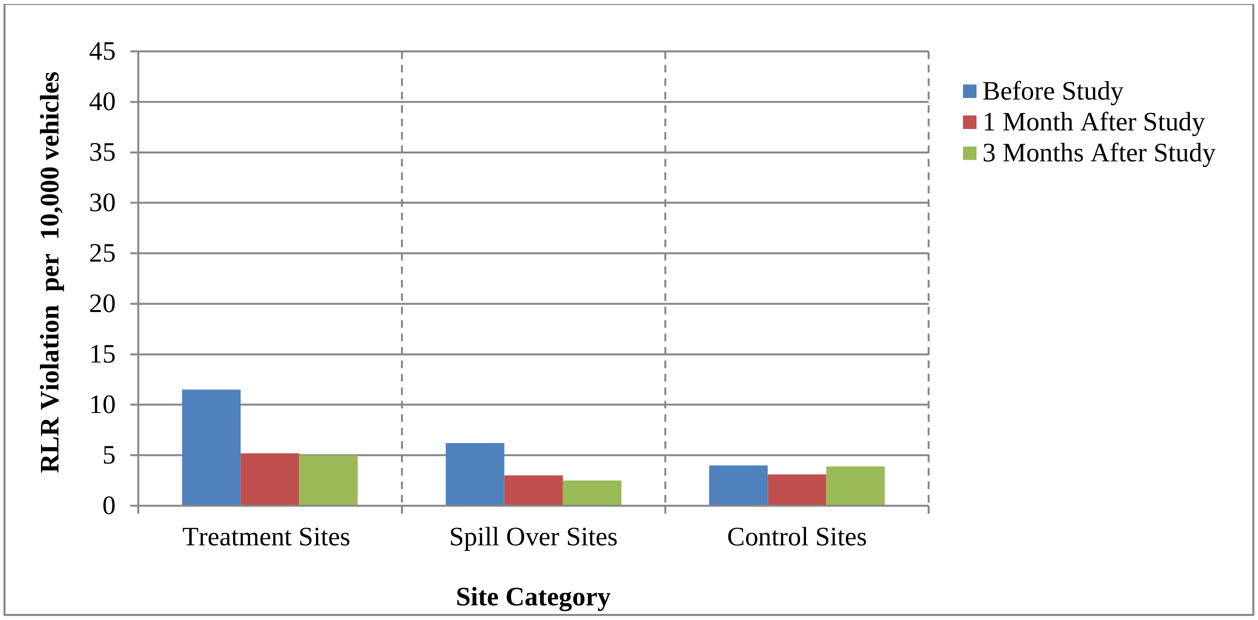

Figure 49. Left-turn RLR violations rates per study intersection for before-after study (Morning).

Figure 50 shows the left-turn RLR violation rates for the evening peak hours. As previously discussed, the treatment sites again saw the highest violation rates as compared to the other two study sites. Overall, one month after the installation of the confirmation lights, the violation rates decreased considerably at the treatment and spillover sites but increased slightly at the control sites. The three months after study saw increases in the violation rates at the treatment and spillover sites but were still lower than the before rates. At the control sites, no significant changes in RLR violation rates were observed during all the study periods.

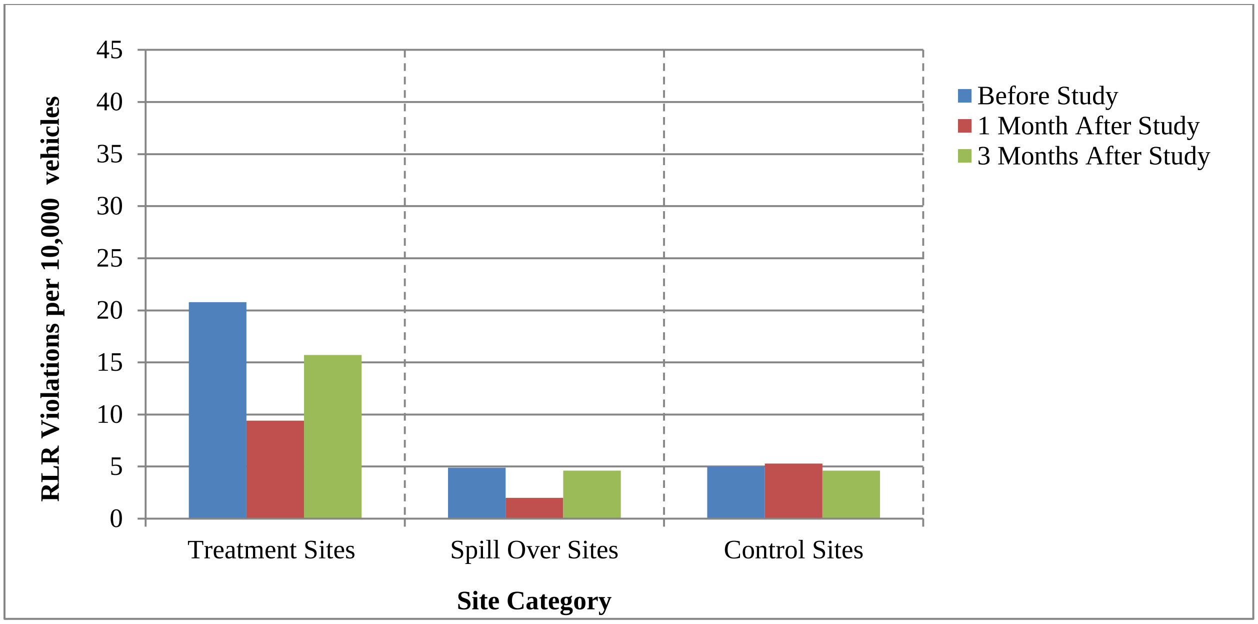

Figure 50. Left-turn RLR violations rates per study intersection for before-after study (Evening)

5.1.3.2 Through-movement RLR Violation Rates

Figure 51 shows the through-movement RLR violation rates for the morning peak hours. As seen in the figure, the treatment sites recorded a significant reduction in RLR violation rates one month after the installation of the confirmation lights but saw a higher increase than the before rate three months after installation. It was observed that as drivers traveling through the intersection became familiar with the confirmation lights, knowing that they were installed to monitor violations for left turn only movements, the drivers reverted to their former driving behavior as time progressed. This explains why the higher increase in violation rates three months-after installation than the one month after period rates. The spillover and the control sites showed the same trend in the violation rates during the study periods. The violation rates at the spillover and control sites increased steadily with the study periods.

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Figure 51.Through-movement RLR violation rates per study intersection for before-after study (Morning).

The evening peak hour RLR violation rates for through-movement is shown in Figure 52. As shown, the treatment sites saw a similar trend in violation rates as previously observed in the morning. The one month after study at the treatment sites saw a great decrease in violation rates but increased substantially during the three months after study. However, this increase was below the before violation rate. The spillover sites saw decrease in violation rate during the one month after study but the rates increased during the three months after study period. This increase was higher than the before violation rate. The control sites showed similar trend in violation rates as was previously seen in the morning.

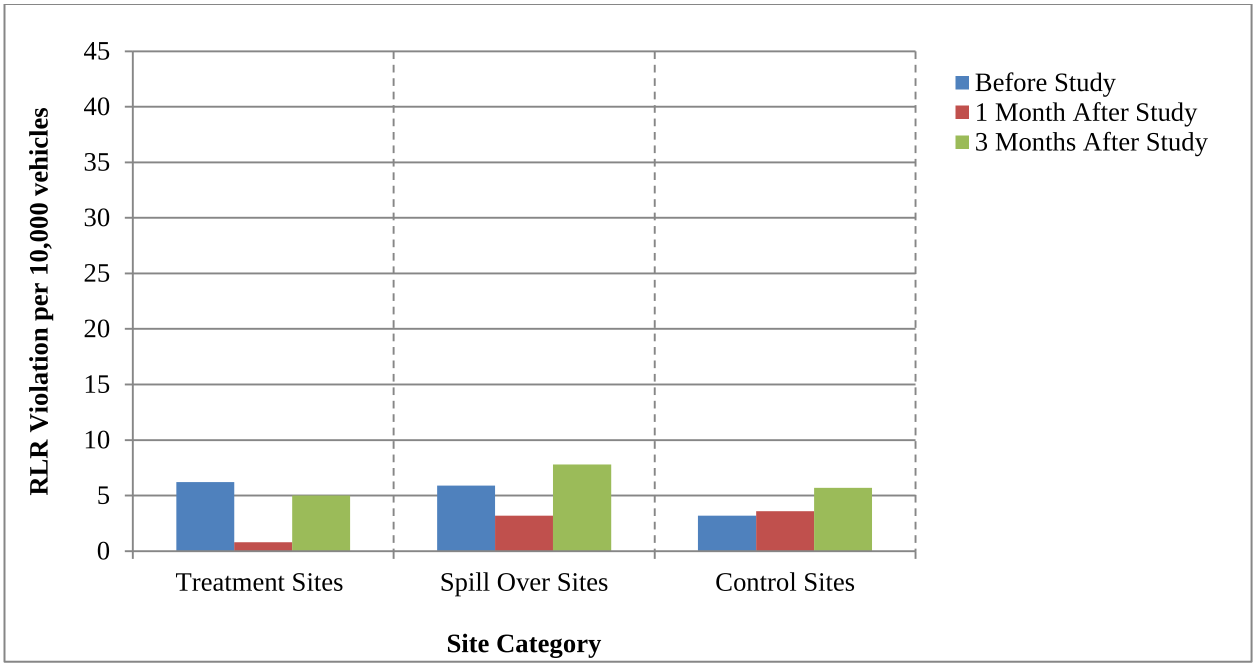


Figure 52. Through-movement RLR violation rates per study intersection for before-after study (Evening).

5.1.3.3 Right-turn Violation Rates

Results of the RLR violation rates for right-turning movements during the morning peak hours are shown in Figure 53. As shown, the treatment and control sites saw considerable reductions in violation rates from the before period to the one month after installation period. Overall, three months after installation of the confirmation lights both treatment and control sites saw increases in violation rates, yet they were still below the before rates. Violation rate at the spillover sites one month after installation increased marginally than the before period but the rates decreased substantially during the three months after study.

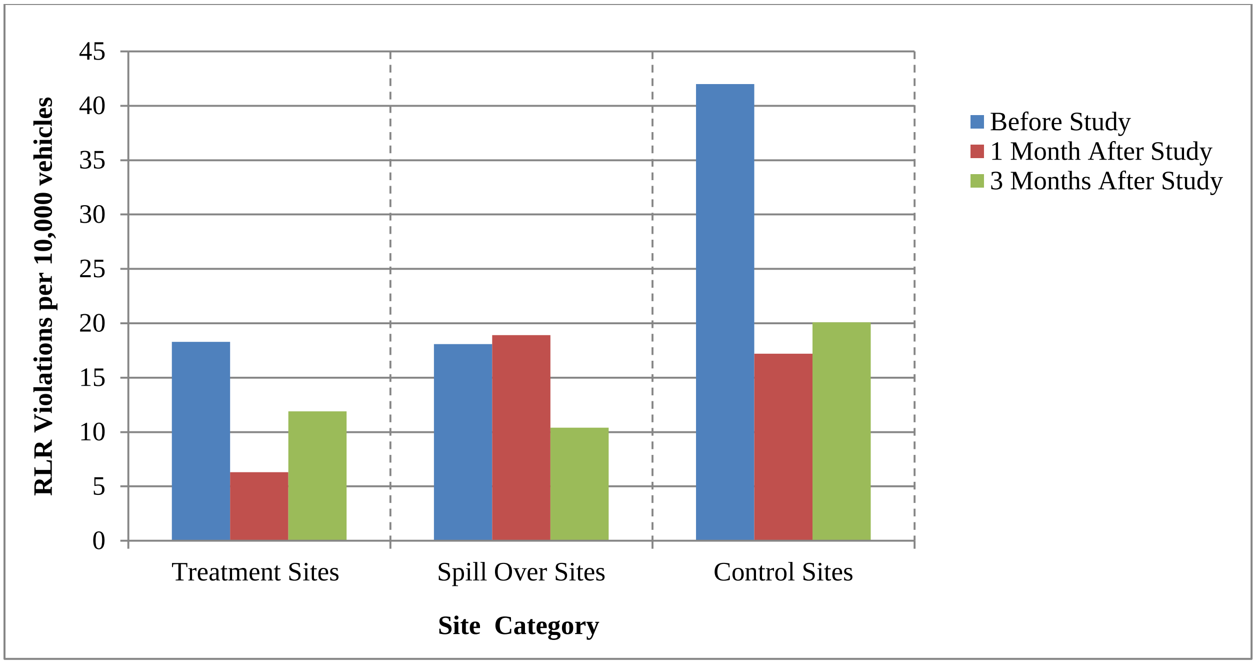


Figure 53. Right-turn RLR violation rate per study intersection for before-after study (Morning).

Figure 54 shows the right-turn violation rates for the evening peak hours. The treatment and spillover sites saw increases in violation rates one month after the confirmation lights were installed. However, during the three months after study, the spillover sites saw a great decrease in violation rate while the treatment sites saw a great increase in violation rate. At the control sites, the one month after study saw higher reduction in violation rate than the three month after study.

At both treatment sites, it was observed that, right-turning movements had geometric constraints that influenced a driver's decision to run a red light. Sight distance was a problem for traffic wanting to make a right-turn on red to join the through traffic stream. Most of the violators were looking laterally at the through traffic stream on the cross street for gaps to join the through traffic after making a right-turn. In doing so, most drivers ignored the right turn signals and ran the red lights. The mechanics involved in making right-turning movements at signalized intersections is complicated. Most drivers would slow down, but not stop and rolled through the intersection thinking that it was safe to do so. This explains why the research team did not observe any trend in the RLR violation rates especially at the treatment sites. Since the results of the right-turn RLR violations did not make sense, no statistical analysis were performed on the results.

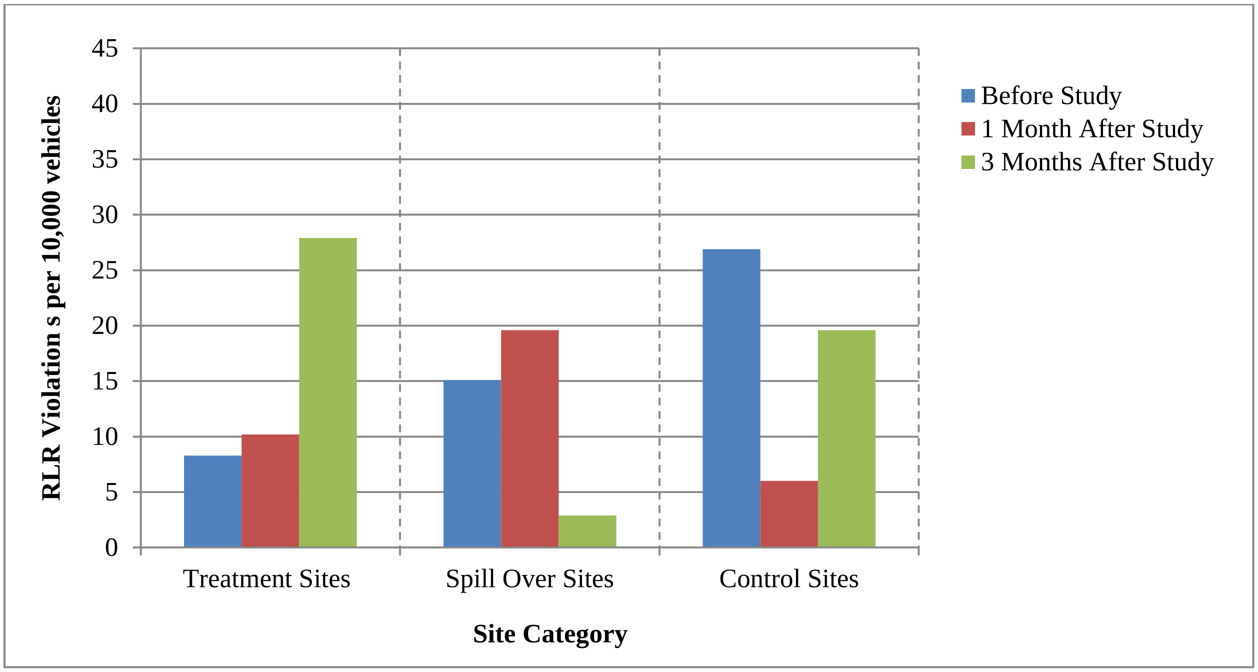


Figure 54. Right turn RLR violation rate per study intersection for before-after study (Evening).

5.2. Violation by Time of the Day

5.2.1 Background

As previously discussed in literature at Chapter 3, the frequency of RLR is significantly influenced by the time of the day. Studies have shown that a majority of red light running occurs during the normal work hours (Kamyab et al., 2000; Retting et al., 1998). Research has shown that during the morning and evening peak hours, drivers tend to run red lights due to being late to work and also being stuck in traffic for long hours (Porter et al., 2000). As part of this study, investigation of the distribution of the RLR violations by time of the day was carried out to determine if the findings of this study were consistent with previous studies. The results of the distribution of the violations by time of the day (15 minutes interval) are presented in the following section.

5.2.2 Results

5.2.2.1 Morning Peak RLR Violation

Figure 55 illustrates the distribution of RLR violation rates by 15 minute time interval from 7 a.m. to 9 a.m. for left-turn and through-movement combined. The overall trend shown this in figure was consistent with the expectation that most RLR occurs during day time hours when majority of drivers commute to work. The highest frequency of the RLR violation rates for each study period occurred between 7:30 a.m. and 8 a.m., which accounted for approximately 30 percent of the total observed RLR violations in the morning peak hours

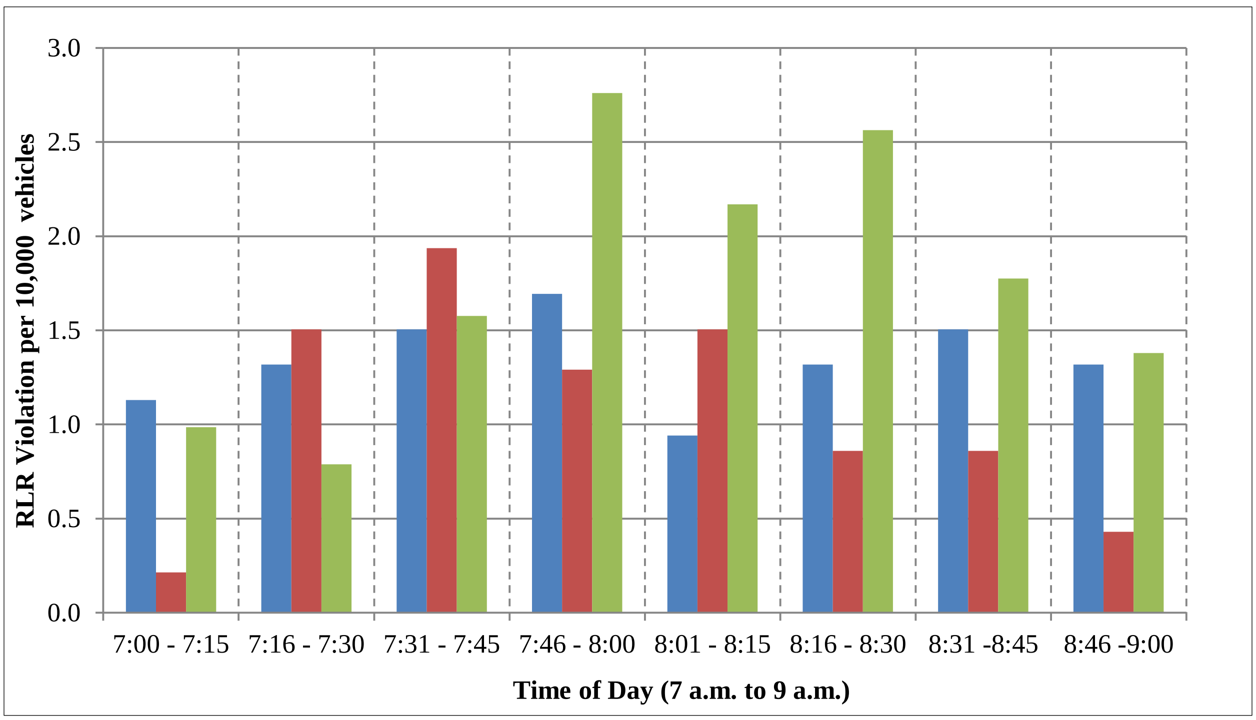


Figure 55. Distribution of RLR violation by time of the day during the morning peak

5.2.3.2 Evening Peak RLR Violation

The frequency of the distribution of RLR violations for the evening peak hours is shown in Figure 56 for the left turn and through movements combined. As shown, the violation rates were prevalent between 5:00 p.m. and 5:30 p.m. for all the study periods. RLR violation rates at this time period accounted for approximately 30 percent of the total observed violations for each study period.

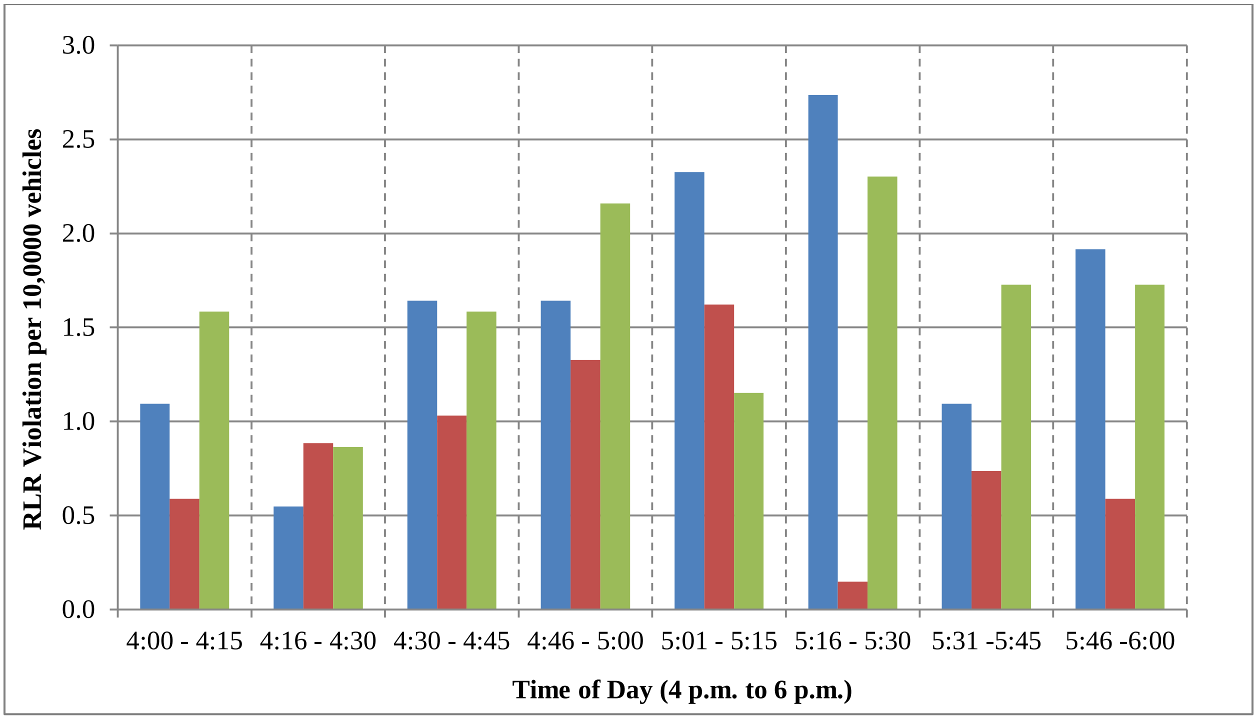


Figure 56. Distribution of RLR violation by time of the day during the evening peak

5.3. Time into Red Analysis

5.3.1 Background

An important aspect to a vehicle running a red light is how long into the red cycle did the violation occur. Violations found within the all-red time (generally one to two seconds) are most likely due to a driver caught in the intersection dilemma zone or at the end of a platoon and intentionally run the red light. The dilemma zone of an intersection is an area prior to the stop bar where the driver is unsure either to stop or proceed through the intersection during the yellow phase.

However, drivers that enter the intersection past the all-red phase create a more dangerous situation, particularly if the conflicting movement has a green light. Hallmark et al. (2012) stated that drivers that run a red light late into the red phase are more likely unintentional and involve a distraction, impairment, or fatigue. Hallmark et al. (2012) also found when evaluating RLR cameras in Cedar Rapids, IA that over 120 of violations occurred from zero to less than one second into the red phase, while over 60 violations occurred 25 seconds into the red phase during a pre-ticket evaluation period of seven intersection approaches. Another research study has found that 95 percent of RLR violations occur in the first two minutes of the red phase (Beeber, 2011).

As explained in detail in the previous chapter, this study investigated the effectiveness of the confirmation light system by determining if the change in RLR violations were statistically significant before and after the confirmation light installation. Effectiveness of the confirmation light system was also extended into investigating the change of the time into red for violations captured by the video data.

5.3.2 Methodology

The time into red was evaluated similar to the previous chapter where the treatment intersections were compared to the spillover and control intersections for three study periods (before, one month after installation, and three months after installation). Additionally, two intersection movements were investigated including left-turning (lights were for this movement at the treatment intersections) and the through movement. The average time into red for each movement was also determined at each treatment, spillover and control site.

Time into red was plotted where the x-axis was the number of violations and the y-axis was time into red (in seconds). Violations were aggregated in the y-axis for seconds with a maximum time plotted of greater than five seconds. It should be noted as stated in the previous section that the number of violations in each study period changed, so the total number of violations plotted in the following figures is not a consistent number for each study period.

5.3.3 Results

5.3.3.1 Left-turning Movement

Figures 57, 58, and 59 show the results of the RLR time into red for the left-turning movement for all of the intersections studied. Figure 57 shows the left-turning movement time into red for the two treatment intersections.

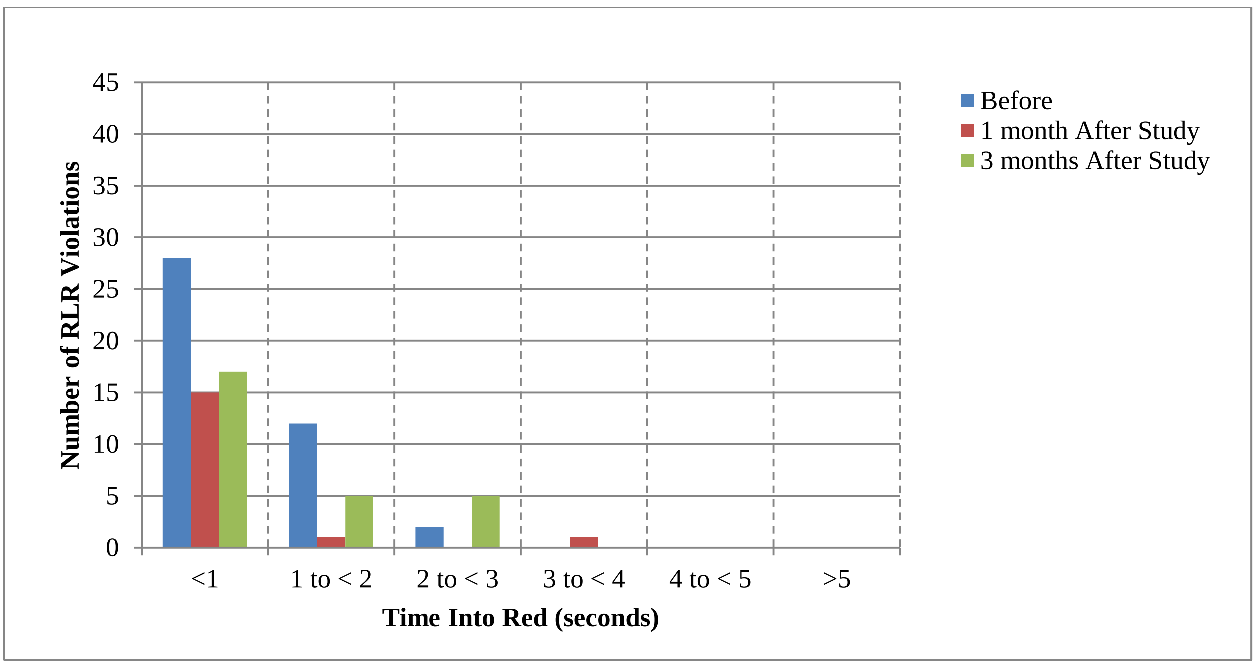


Figure 57. Left-turning movement time into red at treatment intersections

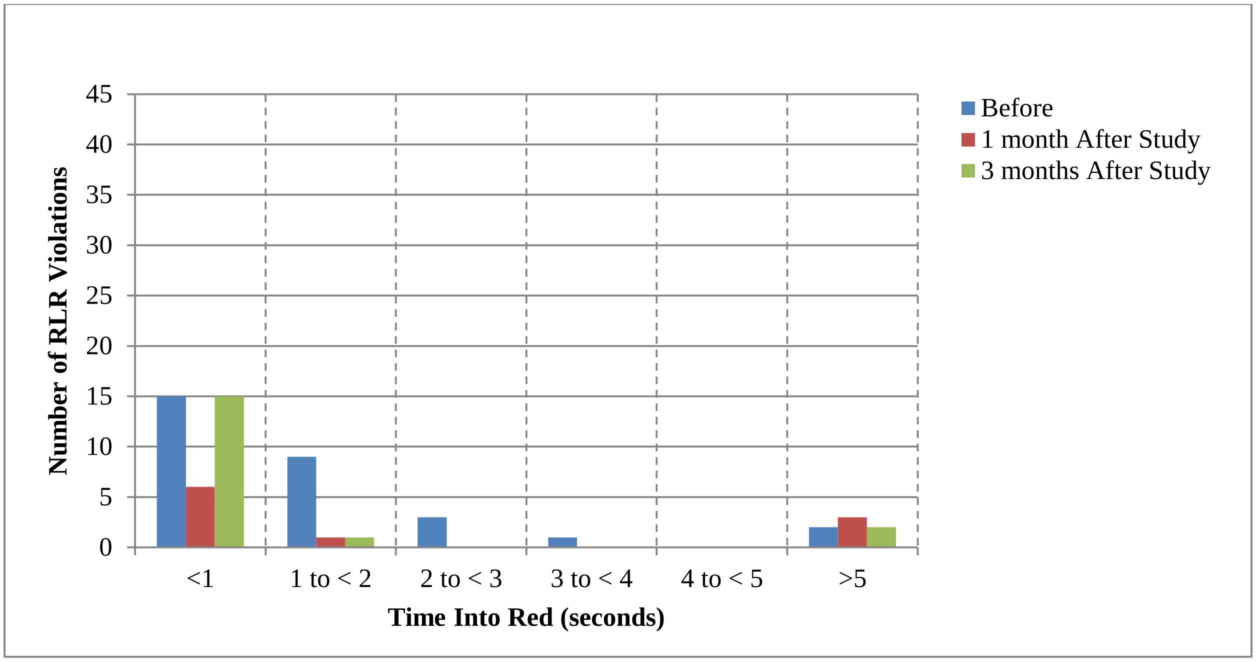


Figure 58. Left-turning movement time into red at spillover intersections

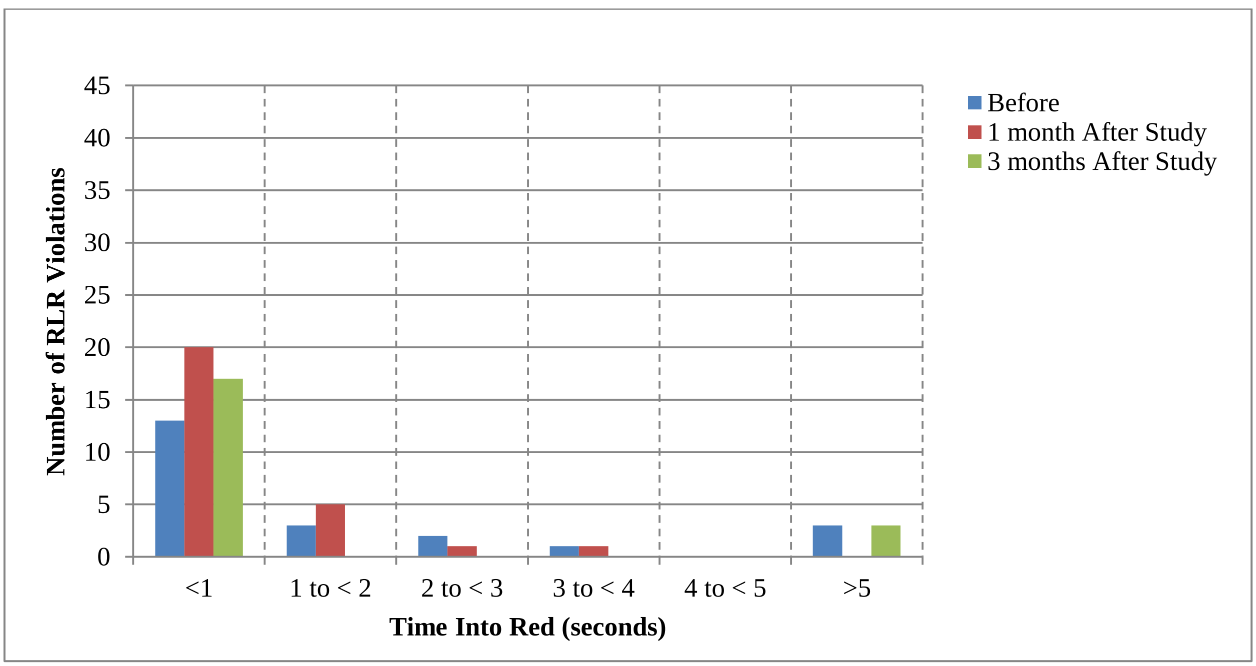


Figure 59. Left-turning movement time into red at control intersections

As shown in Figure 57, most of the violations occurred less than one second after the onset of the red light. The total number of violations happening was reduced after the confirmation lights were installed between periods. It was found that no violations occurred after four seconds during the three study periods indicating that most of the RLR was occurring closer to the all-red phase, decreasing the chances of a crash with a conflicting movement.

Figure 58 shows the left-turning movement time into red at the spillover intersections adjacent to the two treatment intersections. As shown, the overall number of violations was less than the two treatment intersections and no violations occurred in the after periods between four and five seconds. However, the spillover sites saw vehicles running a red light more than five seconds into the red before and after the confirmation lights were installed. This does pose a safety concern as these drivers were entering the intersection while the conflicting traffic had a green light.

Figure 59 shows the left-turning movement time into red at the control intersections. Similar to the previous two figures, most of the RLR violations occurred less than one second after the red light shown. However, similar to the spillover intersections, it was found that RLR violations were occurring after five seconds into the red light before and after the confirmation lights were installed at the treatment intersections. This also poses a safety concern at these intersections as drivers were running the red light during the start of the green phase for conflicting traffic movements.

5.3.3.2 Through Movement

Figures 60, 61, and 62 show the results of the time into red for the through movement violations at all of the intersections studied. Figure 60 shows the through-movement violations' time into red for the two treatment intersections.

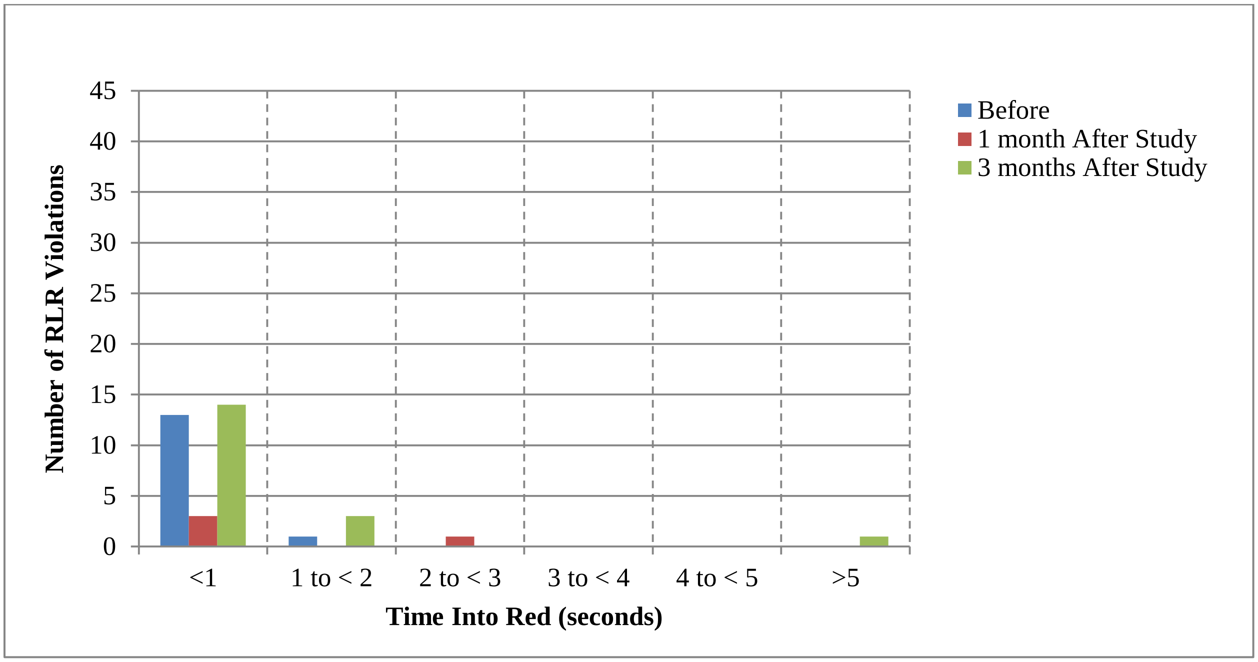


Figure 60. Through-movement time into red at treatment intersections

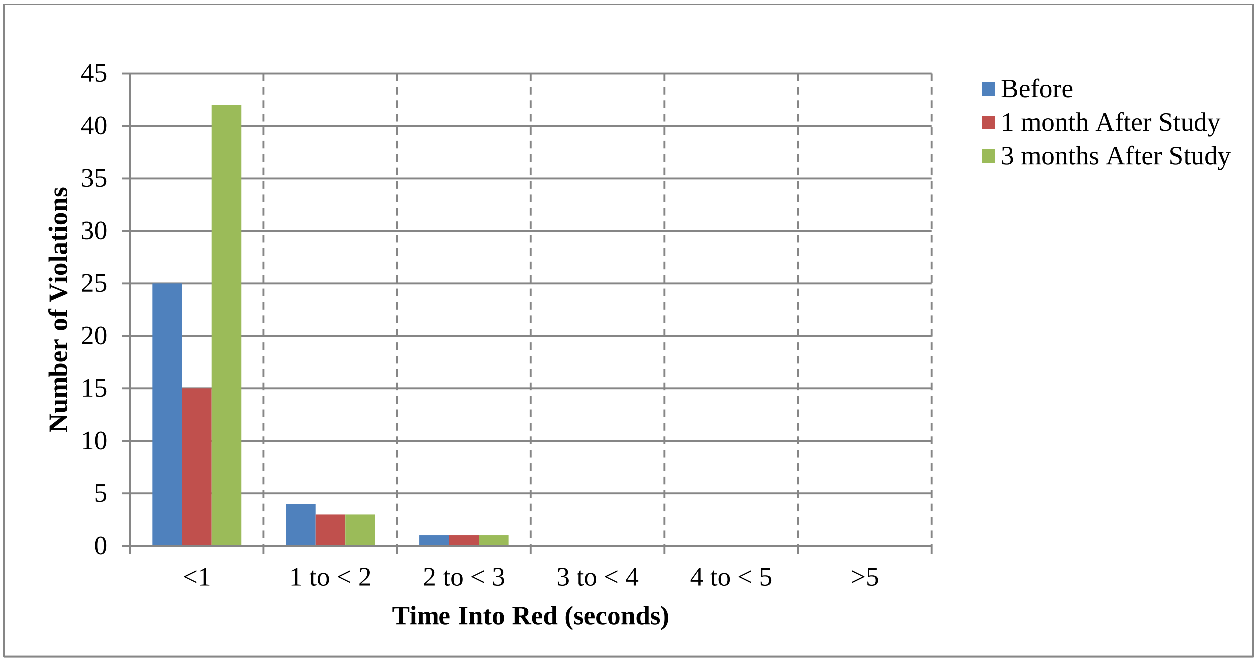


Figure 61. Through-movement time into red at spillover intersections

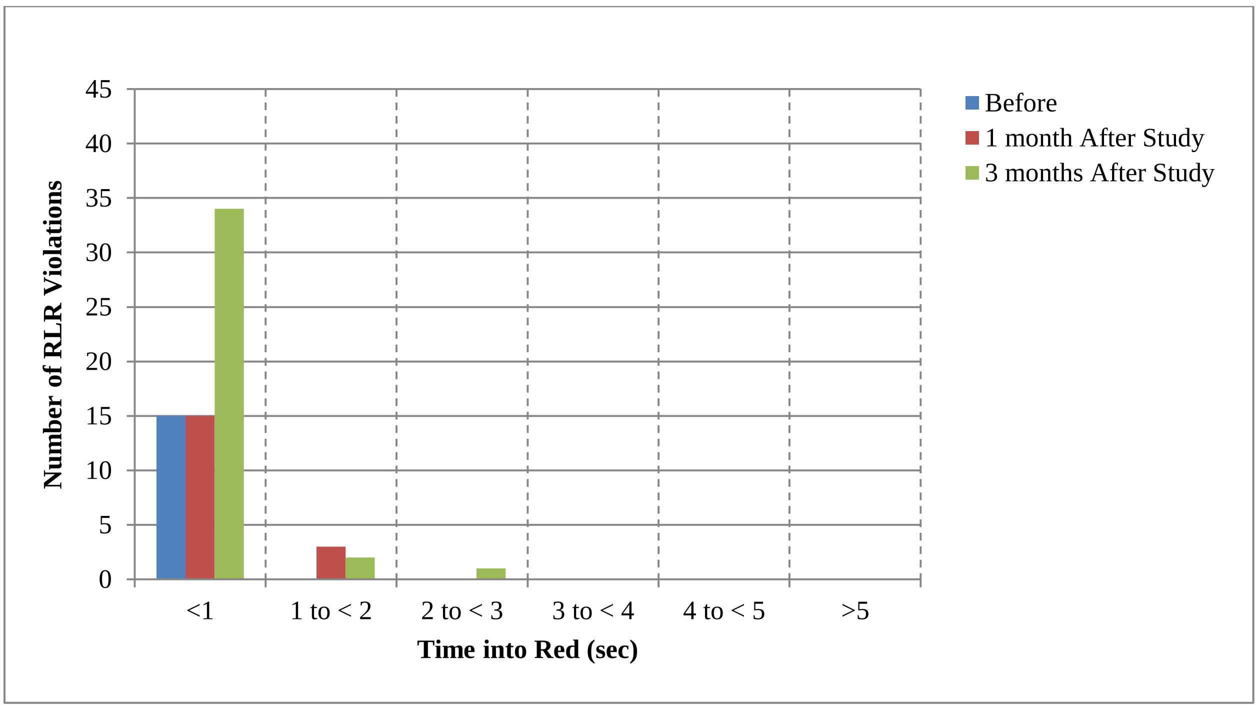


Figure 62. Through-movement time into red at control intersections

As shown in Figure 60, most of the through-movement violations occurred under a second into the red at the treatment intersections. Other violations were found to occur between one and three seconds into the red. The research team did find violations occurring after five seconds into the red 3 months after installation, meaning there were some unintentional violations during that period.

Figure 61 shows the through-movement RLR violations at the spillover intersections. Similar to the treatment intersections, most of the through-movement violations occurred under one second into the red, and no violations were found after three seconds into the red indicating that the violations were intentional.

Similar to the treatment and spillover intersections, the control intersections saw many through-movement violations occurring less than one second into the red phase indicating that RLR violations were intentional. Violations between one and three seconds into the red were observed at the control sites which was also common at the other two site categories. No violations occurred after 5 seconds into the red at the control intersections during any of the study periods as shown in Figure 62.

5.4. Violation Configurations and Vehicle Types

5.4.1 Background

How do RLR violations occur? Are the violations committed by a driver of a single vehicle or multiple vehicles traveling in a platoon or side by side and violating the red aspect of the traffic signal together? As previously reviewed from the literature, little or no studies have been conducted to address these questions. This study investigated how the RLR violations which were recorded during the before-after study periods occurred. Retting et al. (1996)

reported in their study that most red light runners were more likely to be drivers driving small cars One of the focuses of this study was to investigate the types of vehicles driven by the red light runners.

5.4.2 Methodology

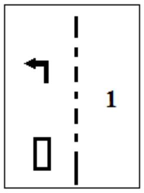
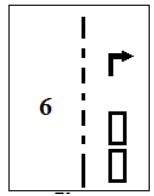
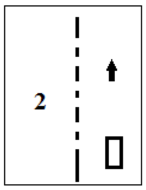
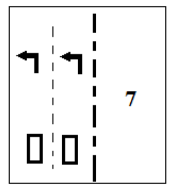
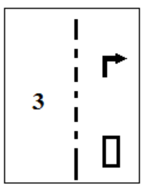
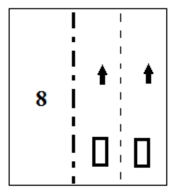
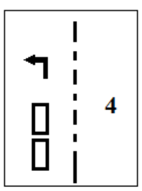
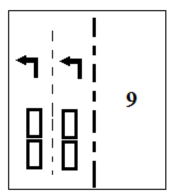
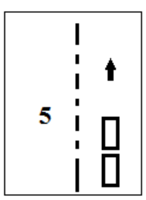
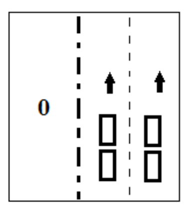
During the field video data reductions, students were also given guidelines to group the violations by the configuration types shown in Figure 43. The violation configurations were coded 0 to 9 and were explained to each student using Table 17 as well. Additionally, students were then asked to record the type of vehicle involved in the RLR violation. The types of vehicles included passenger cars, buses, trucks and recreational vehicles.

5.4.3 Results

5.4.3.1 Violation Configurations

Table 18 shows the number of violations (in percentage) for each of the ten configuration types during the study periods. Morning and evening peak hour violations for all the 13 study intersections were combined. For each configuration type, the percentage of RLR violations were then calculated by dividing the number of violations that occurred in that configuration type by the total number of violations for that study period and multiplying the result by 100. For example, if 82 violations were recorded for the violation type coded 1 during the before study, and the total number of violations observed was 420, then the percentage of the violations that occurred for configuration type 1 was expressed as (82/420)*100, yielding 20 percent. RLR violation by configuration type was not considered by site category. All the violations for the treatment, spillover and control sites were combined for the before, one month after (1 mo) and three months after (3 mo) study periods, respectively.

Table 18. Violation Configuration

Violation Configuration	Violations in percentage			Violation Configuration	Violations in percentage		
	Before	1 mo	3 mo		Before	1 mo	3 mo
	20%	22%	18%		5%	3%	6%
	14%	16%	29%		2%	0%	0%
	58%	58%	43%		0%	0%	1%
	1%	1%	0%		0%	0%	1%
	0%	0%	2%		0%	0%	0%

From Table 18, it was found that a single vehicle making a right-turn (coded 3) showed the highest percentage of RLR violations across all the study periods. This violation type accounted for 40 to 60 percent of all the violations observed during the three study period (before, one month after installation, and three months after installation).It was observed that at locations where right-turns on red were permitted, the majority of the drivers rolled through the intersections without initially coming to a complete stop.

A single vehicle making a left-turn (coded 1) showed the second highest percentage of RLR violations during the before and one month after study periods, followed by a single vehicle traversing through the intersection (coded 2). However, during the three months after study, the through-movement violation by a single vehicle showed a higher percentage in RLR violation than a single vehicle making a left-turn.

As shown in Table 18, violation configuration types 4, 5, 7, 8 and 9 saw less than three percent of the total violations observed for each before-after study period. This small percentage showed that drivers following too closely to each other in a platoon or traveling side by side seldom ran the red lights together. However, the violation configuration type 6 (a platoon of vehicles making a right turn) saw three to six percent of the total observed violations during the before-after study periods. No violations were recorded for violation configuration type 0.

5.4.3.2 Violation by Vehicle Type

The percentages of RLR violations categorized by type of vehicle driven by the violators are shown in Table 19. Over 98 percent of the RLR violations were committed by drivers of passenger cars during all the study periods. This finding is consistent with a previous study by Retting et al. (1996), where they reported that drivers who run red lights were more likely to be driving small vehicles. From Table 19, it is shown that trucks and buses accounted for less than two percent of the entire vehicles that were involved in RLR. There was no instance of a recreational vehicle running a red light during each study period.

Table 19. RLR Violation by Vehicle Type

Vehicle Type	RLR Violations		
	Before	**1 mo**	**3 mo**
Passenger Car	99.3%	98.4%	99.7%
Truck	0.5%	1.6%	0.3%
Bus	0.2%	0.0%	0.0%
Recreational Vehicle	0.0%	0.0%	0.0%

CHAPTER 6: STATISTICAL ANALYSIS OF RLR VIOLATIONS

6.1 Comparison of RLR Violation Rates after Installation of Confirmation Lights.

Studies that have assessed the effectiveness of a roadway safety device rely on a before-after crash analysis. These studies involve at least three years of before data and three years of after data (Nicholson, 1985). However, many communities want to know the effectiveness of a device or treatment shortly after installation to determine if the investment in the device was a good decision. Many times, in place of a before-after crash analysis, researchers will use a safety surrogate measure in its place.

Researchers have previously used the reduction in RLR violations as a crash surrogate for a reduction in RLR crashes. This relationship is not direct due to the fact that RLR violations occur more frequent than RLR crashes since they are rare and random events. Research has also shown that red light runners tend to have common traits such as age, driving experience, speed convictions, and vehicle type (Retting and Williams, 1996). However, a reduction in violations means there is a reduction in exposure, or a reduction in the chances of a RLR crash to occur.

Additionally, besides considering a change in RLR violations before and one month after the confirmation lights were installed, a change in violations three months after installation was investigated. Unlike previous research studies, it is unknown if the confirmation lights (or really any safety countermeasure) become less effective over time as drivers become accustom to the treatment and associated enforcement. However, changes in driver behavior or changes in enforcement using the confirmation lights may be more effective over time.

6.2 Methodology

The RLR violation rate was the metric used to compare changes during the before, 1 month after, and 3 months after installation of the confirmation lights. Violation rate was used instead of the number of violations to account for varying intersection volumes (exposure). RLR rate was expressed in 10,000 entering vehicles as shown previously in Equation 1.

Once a violation rate was determined for each data collection period, a change in the violation rates was determined using Equation 4.

$$\boldsymbol{Change}\ (\%) = \frac{\boldsymbol{\hat{\pi}_i - \hat{\pi}_b}}{\boldsymbol{\hat{\pi}_b}} \times \mathbf{100}\% \qquad \textbf{Eq. 4}$$

Where: $\hat{\pi}_b$= violation rate for before period

$\hat{\pi}_i$ = violation rate for after period *i*

To compare the calculated rates for the before, 1 month, and 3 months after installation of the confirmation lights, a test of proportions was used to determine if the changes in rate were statistically significant. The Z statistic test was chosen because it was the appropriate method to determine the differences between the two sample proportions (before and after data) which approximately followed a normal distribution. Equation 5 was used to perform this step of the analysis.

$$\boldsymbol{Z} = \frac{(\boldsymbol{\hat{\pi}_b - \hat{\pi}_i})}{\sqrt{\frac{\boldsymbol{\hat{\pi}_b(1-\hat{\pi}_b)}}{\boldsymbol{n_b}} + \frac{\boldsymbol{\hat{\pi}_i(1-\hat{\pi}_i)}}{\boldsymbol{n_i}}}} \qquad \textbf{Eq. 5}$$

Where: Z = z-test statistic

$\hat{\pi}_b$= violation rate for before period

n_b = volume for before period

$\hat{\pi}_i$= violation rate for after period *i*

n_i = volume for after period *i*

The calculated z-test statistic was compared to a Z table with α = 0.05 to determine significance at the 95 percent level of confidence. If the Z was greater than 1.96, the resulting *decrease* in violation rate was statistically significant. Similarly, if the Z was less than -1.96 the resulting *increase* in violation rate was statistically significant.

6.3 Results of RLR Violations

The results of the violation study for all intersections are presented in this section. As stated previously, the blue confirmation lights were installed at two intersections for the left-turning movement. A total of six approaches were treated, four at the intersections of 23rd Street and Iowa Street and two at the intersection of 23rd Street and Louisiana Street.

Since the intersection of 23rd Street and Iowa Street had two approaches that were not treated with the blue confirmation light, it was determined that these two approaches would be considered as "not treated approaches" and would act as immediate spillover sites. Additionally, six spillover and five control intersections were investigated. The changes in violations for left-turning movement and through-movement were evaluated separately and the results are presented in the following sections.

6.3.1 Analysis of Left-turning Movement Red Light Running Violations

Table 20 shows the results of the analysis for the left-turning movements only. Morning and evening peak hours were combined. The table shows: the intersection, RLR violations recorded, number of vehicles counted, RLR rates per 10,000 vehicles, and percent change in violation rates between periods. For the percent change in violation rates, a period represents an infinite change. A total change in RLR rates is the average rate for the treatment site, treatment site with no confirmation lights, spillover sites, and control sites.

Table 20. Results of the RLR Violation Analysis for Left-turning Movements

	Number of Violations			Number of Vehicles			Violations/TEV			Percent Change	
Treatment Site (Treated App.)	**Before**	**1 mo**	**3 mo**	**Before**	**1 mo**	**3 mo**	**Before**	**1 mo**	**3 mo**	**1 mo**	**3 mo**
23rd Street & Iowa Street (NB)[B]	6	1	1	3,007	2,059	2,249	20	4.9	4.4	-75.7	-77.7
23rd Street & Iowa Street (SB)[B]	19	8	9	3,236	2,448	2,533	58.7	32.7	35.5	-44.3	-39.5
23rd Street & Iowa Street (WB)[B]	2	2	5	2,948	2,881	3,092	6.8	6.9	16.2	2.3	138.4
23rd Street & Iowa Street (EB)[B]	6	0	4	3,759	3,288	3,838	16	0	10.4	-100.0[A]	-34.7
23rd Street &Louisiana Street (WB)[B]	2	3	3	4,232	3,853	4,510	4.7	7.8	6.7	64.8	40.8
23rd Street & Louisiana Street (EB)[B]	5	1	0	4,108	4,234	4,211	12.2	2.4	0	-80.6	-100.0[A]
Total	**40**	**15**	**22**	**21,290**	**18,763**	**20,433**	**18.8**	**8**	**10.8**	**-57.4[A]**	**-42.7[A]**
Treatment Site (Non-Treated)											
23rd Street & Louisiana Street (NB)[B]	2	2	4	1,915	1,971	1,932	10.4	10.1	20.7	-2.8	98.2
23rd Street & Louisiana Street (SB)[B]	0	0	1	1,619	1,558	1,691	0	0	5.9	•	•
Total	**2**	**2**	**5**	**3,534**	**3,529**	**3,623**	**5.7**	**5.7**	**13.8**	**0.1**	**143.9**
Spillover Sites											
23rd Street & Ousdahl Road	3	1	1	9,609	5,697	8,338	3.1	1.8	1.2	-43.8	-61.6
19th Street & Iowa Street	20	5	8	11,609	7,580	9,308	17.2	6.6	8.6	-61.7[A]	-50.1
19th Street & Louisiana Street	4	3	7	6,203	6,312	6,732	6.4	4.8	10.4	-26.3	61.2
Clinton Parkway & Crestline Drive	0	0	0	8,719	7,191	8,789	0	0	0	•	•
25th Street & Iowa Street	1	1	0	7,471	5,332	5,478	1.3	1.9	0	40.1	-100
23rd Street & Alabama Street	1	0	2	9,552	9,282	9,652	1	0	2.1	-100	97.9
Total	**29**	**10**	**18**	**53,163**	**41,394**	**48,297**	**5.5**	**2.4**	**3.7**	**-55.7[A]**	**-31.7**
Control Sites											
6th Street & Kasold Drive	3	5	3	10,977	11,753	9,948	2.7	4.3	3	55.7	10.3
6th Street & Michigan Street	5	1	1	9,511	8,674	9,752	5.3	1.2	1	-78.1	-80.5
31st Street & Iowa Street	0	1	1	8,668	7,434	8,612	0	1.3	1.2	•	•
6th Street & Wakarusa Drive	3	0	2	8,061	7,402	7,722	3.7	0	2.6	-100	-30.4
Clinton Parkway & Kasold Drive	11	14	14	11,030	12,138	12,442	10	11.5	11.3	15.7	12.8
Total	**22**	**21**	**21**	**48247**	**47401**	**48476**	**4.6**	**4.4**	**4.3**	**-2.8**	**-5**

[A]Change in violation rate is statistically significant at the 95 percent level of confidence
[B]NB, SB, WB, EB denotes northbound, southbound, westbound, and eastbound respectively

Overall, the blue confirmation lights showed promising results at the treatment intersections/approaches for left turning movements. Two of the left-turn treated approaches saw an increase in violations while four approaches saw a decrease in violations. When the total change in left-turning violations at all treated approaches was compared, the number of left-turning violations decreased, and it was statistically significant at the 95 percent level of confidence.

The results indicated that the two left-turning intersection approaches that experienced an increase at both treatment intersections were westbound. Based on heavy commuter traffic both eastbound and westbound at both intersections, it can be speculated that commuter traffic during the peak hours may have influenced the increase in RLR violations for this movement. Overall, the decrease in left-turn RLR violation rates were substantial with east and northbound approaches having a greater than 40 percent reduction in left-turning RLR violations with eastbound approaches having a 100 percent reduction in violations.

The northbound non-treated intersection approach at the intersection of 23th Street and Louisiana Street saw a minor decrease (1 month after) and a major increase (3 months after) in left-turning RLR violations. It should be noted that substantial increase in the violation rates did not represent a significant safety issue due to small numbers of violations observed for that approach.

The spillover intersections found an overall reduction in left-turn RLR violations at the spillover intersections. Similar to the non-treated intersection approaches, many of the spillover intersections saw minimal RLR violations. However, based on an overall analysis, it can be speculated that driver behavior may have changed due to the confirmation lights being present at the treatment intersections located nearby. It should be noted that a substantial reduction in left-turning RLR violations occurred at the spillover intersection of 19th Street and Iowa Street, and that the blue lights can clearly be seen by the drivers at this intersection.

Analysis of the data showed a slight decrease in left-turn RLR violations at the control intersections located far away from the treatment and spillover intersections. As shown, the intersection of Clinton Parkway and Kasold Drive saw a large number of left-turning RLR violations throughout the study, indicating that although this was a positive effect in the reduction of RLR violations, there are some major intersections in Lawrence that are seeing an increase.

6.3.2 Analysis of Through-movement RLR Violations

Table 21 shows the results of the analysis for the through movements only. The morning and evening peak hours were combined. Table 21 shows: the intersection, RLR violations recorded, number of vehicles counted, RLR rates per 10,000 vehicles, and percent change in violation rates between periods. For the percent change in violation rates, a period represents an infinite change. A total change in RLR rates is the average rate for the treatment site, treatment site with no confirmation lights, spillover sites, and control sites

Table 21. Results of the RLR Violation Analysis for Through Movements

	Number of Violations			Number of Vehicles			Violations/TEV			Percent Change	
Treatment Sites	Before	1 mo	3 mo	Before	1 mo	3 mo	Before	1 mo	3 mo	1 mo	3 mo
23rd Street & Iowa Street	11	1	9	12,950	10,676	11,712	8.5	0.9	7.7	-89.0[A]	-9.5
23rd Street & Louisiana Street	3	1	9	11,874	11,616	12,344	2.5	0.9	7.3	-65.9	188.6
Total	**14**	**2**	**18**	**24,824**	**22,292**	**24,056**	**5.6**	**0.9**	**7.5**	**-84.1[A]**	**32.7**
Spillover Sites											
23rd Street & Ousdahl Road	3	1	9	9,609	5,697	8,338	3.1	1.8	10.8	-43.8	245.7
19th Street & Iowa Street	9	2	12	11,609	7,580	9,308	7.8	2.6	12.9	-66	66.3
19th Street & Louisiana Street	0	0	2	6,203	6,312	6,732	0	0	3	•	•
Clinton Parkway & Crestline Drive	5	1	1	8,719	7,191	8,789	5.7	1.4	1.1	-75.8	-80.2
25th Street & Iowa Street	8	4	10	7,471	5,332	5,478	10.7	7.5	18.3	-29.9	70.5
23rd Street & Alabama Street	5	12	12	9,552	9,282	9,652	5.2	12.9	12.4	147	137.5
Total	**30**	**20**	**46**	**53,163**	**41,394**	**48,297**	**5.6**	**4.8**	**9.5**	**-14.4**	**68.8[A]**
Control Sites											
6th Street & Kasold Drive	3	4	6	10,977	11,753	9,948	2.7	3.4	6	24.5	120.7
6th Street & Michigan Street	4	4	12	9,511	8,674	9,752	4.2	4.6	12.3	9.6	192.6[A]
31st Street & Iowa Street	1	0	1	8,668	7,434	8,612	1.2	0	1.2	-100	0.7
6th Street & Wakarusa Drive	4	5	4	8,061	7,402	7,722	5	6.8	5.2	36.1	4.4
Clinton Parkway & Kasold Drive	3	4	9	11,030	12,138	12,442	2.7	3.3	7.2	21.2	166
Total	**15**	**17**	**32**	**48,247**	**47,401**	**48,476**	**3.1**	**3.6**	**6.6**	**15.4**	**112.3[A]**

[A]Change in violation rate is statistically significant at the 95 percent level of confidence

As shown in Table 21, the treatment intersections saw a decrease in RLR violation one month after installation of the confirmation lights. An increase in violation rate was observed at 23rd Street and Louisiana Street and a decrease in violation rate at 23rd Street and Iowa Street during the three months after study. An overall reduction in through-movement RLR violations of 84.1 percent was found in the one month after study and a 32.7 percent increase in through-movement RLR violations for the three months after study period. It is speculated that the through-movement traffic noticed the blue lights immediately after installation and then got accustomed to the treatment. The decrease in through-movement RLR violations for the intersection of 23rd Street and Iowa Street as well as the overall decrease in through-movement red light running violations for one month after study was statistically significant at the 95 percent level of confidence.

The spillover intersections followed a similar trend as the treatment intersections in that the through-movement RLR violations decreased one month after the blue confirmation light installation and then saw an increase in through-movement RLR violations for the three month study. It should be noted that the decrease was smaller than the treatment intersections and the increase was larger (and statistically significant at the 95 percent level of confidence) as compared to the treatment intersections.

Considering the control intersections, it was found that through-movement RLR violations increased in both study periods, with the overall three month percentage being statistically significant at the 95 percent level of confidence. In general, the blue confirmation lights had a positive impact on the RLR violations for the through-movement traffic at the treatment and spillover intersections even though the lights were installed for the left-turning movements only.

6.4 Before-After Effect on Violation Time into Red

A secondary performance matrix that was used in evaluating the confirmation lights was the violation time into red, which was defined as the time elapsed prior to a violation occurring. Studies have shown that RLR violations occurring more than two seconds after the red signal indication are more dangerous compared to violations occurring less than a second after the all-red phase (Fitzsimmons et al., 2007; Lum and Wong, 2003). During an all-red phase, vehicles that enter the intersection less than a second after the red indication normally clear the intersection before vehicles currently stopped at the cross street get the green light to start. In such instances, drivers of vehicles in the cross street are not exposed to potential conflicts that could result in crashes. However, drivers who enter the intersection late may put themselves and other road users at risk. An analysis of a before-after effect on RLR violation time into red was conducted to determine whether confirmation lights have the potential to change driver behavior when a violation occurred. The null and alternate hypotheses were stated respectively as:

H_o : Confirmation lights have no effect on the frequency of RLR violation time into red

H_a: Confirmation lights have effect on the frequency of RLR violation time into red

6.5 Methodology

After the video data were reduced, RLR violations for left-turn and through-movement were combined and categorized into two groups. Group 1 consisted of all the RLR violations which occurred within two seconds after the onset of the red signal and group 2 consisted of the violations which occurred more than two seconds after the red indication. Two seconds was chosen because in the City of Lawrence, a minimum of 1.5 seconds is used for the all red interval. This means that any RLR violation after 1.5 seconds into red has a high probability of resulting in a RLR crash. Due to the small sample size of the RLR violation time into red, 2x2 contingency tables were used for analyzing the data for each site category (treatment, spillover, and control sites). Table 22 shows an example of the 2x2 contingency table with the frequency of RLR violations, which occurred less than two seconds and after two seconds during the before and one month after study periods at the treatment sites.

Table 22. Contingency Table for RLR Violation Frequency at the Treatment Sites.

Study period	**Number of Violations**		**Total**
	≤ 2 seconds	**> 2 seconds**	
Before	54	2	56
1 month after	17	2	19
Total	71	4	75

After developing the 2x2 contingency tables for each study site, a Chi Square Test of Independence was chosen as the statistical method to determine if there exists a relationship between the two nominal variables: violation times after red indication, and before-after violation period. The Chi Square statistic was chosen because it was the appropriate method to compare counts of categorical responses between the two independent groups (before and after study periods). This analysis was completed with the understanding that confirmation lights may have an effect on the frequency of dangerous RLR violations at signalized intersections. The formula for the Chi Square Test of Independence is shown in Equation 6.

$$\chi^2 = \sum \frac{(E - O)^2}{E} \qquad \textbf{Eq. 6}$$

Where χ^2 = calculated Chi Square value

E = expected frequency of RLR violation

O = observed frequency of RLR violation

In order to find the Chi Square value, the expected frequency for each column i and row j in Table 22 was calculated using Equation 7.

$$\boldsymbol{E_{ij}} = \frac{\boldsymbol{T_i \times T_j}}{\boldsymbol{N}} \qquad \textbf{Eq. 7}$$

Where E_{ij} **=** the expected frequency for the cell in the i^{th} row and the j^{th} column,

T_i **=** the total number of subjects in the i^{th} row

T_j= the total number of subjects in the j^{th} column

N = the total number of subjects in the table.

Table 23.shows the expected frequencies for the cells in Table 22.

Table 23. Expected Frequencies

Study Period	**Number of Violations**		**Total**
	≤ 2 seconds	**> 2 seconds**	
Before	53.01	2.99	56.00
1 month after	17.99	1.01	19.00
Total	71.00	4.00	75.00

The Chi Square value was computed as follows:

$$\boldsymbol{\chi^2} = \sum \frac{\boldsymbol{(E-O)^2}}{\boldsymbol{E}} = \frac{(53.01-54)^2}{53.01} + \frac{(2.99-2)^2}{2.99} + \frac{(17.99-17)^2}{17.99} + \frac{(1.01-2)^2}{1.01} = \mathbf{1.36}$$

6.6. Results

6.6.1 Chi Square Test for Before and 1 Month After Study

Table 24 shows the Chi Square Test result for the before and one month after study periods. As shown, the numbers of RLR violations which occurred within two seconds after the red indication were higher than the number of violations which occurred more than two seconds after the red indication at all the study sites. It can be seen from Table 24 that, most of the before violations reduced substantially one month after installation of the confirmation lights. The Chi Square statistical analysis showed p-values greater than 0.05 indicating that there were no statistical significant changes in the before-after violation time into red at all the study sites. This means that the confirmation lights one month shortly after installation did not have any significant effect on drivers' behavior of entering the intersections early or late after the red signal was indicated.

Table 24. Chi Square Test for Before and 1 Month after Study

Site Category	Study Period	Number of Violations		Chi-square Value	P-value
		≤ 2 seconds into red	>2 seconds into red		
Treatment	Before	54	2	1.36	0.24
	1 month after	17	2		
Spillover	Before	52	7	0.04	0.84
	1 month after	26	4		
Control	Before	31	6	2.48	0.12
	1 month after	37	2		

6.6.2 Chi Square Test for Before and 3 Months After Study

Table 26 shows the results of the Chi Square Test and their associated p-values for the before and three months after violation time into red at the treatment, spillover and the control sites. As previously discussed, more RLR violations occurred within two seconds after the red indication than the number of violations which occurred more than two seconds after the red indication. At all the study intersections, the statistical tests showed p-values greater than 0.05. This indicated that the confirmation lights did not have any effect on the frequency of RLR violation time into red at the 95 percent level of confidence. Considering the City of Lawrence, the control sites did not see any difference in the violation time into red before and after the confirmation lights were installed. Overall, there was no change in the violation time into red after the installation of this countermeasure indicating that this countermeasure cannot change driver behavior when the violations occur.

Table 25. Chi Square Test for Before and 3 Months After Study

Site Category	Study Period	Number of Violations		Chi-square Value	P-value
		≤ 2 seconds into red	>2 seconds into red		
Treatment	Before	54	2	3.26	0.07
	3 month after	39	6		
Spillover	Before	52	7	2.12	0.15
	3 month after	61	3		
Control	Before	31	6	1.66	0.20
	3 month after	49	4		

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

RLR continues to be a safety concern for many communities in the United States. The consequences of RLR violations each year results in hundreds of fatalities and severe injury crashes. Many communities have turned to automated red light cameras (high-cost countermeasure) which studies have shown to be an effective system in reducing RLR violations and related crashes. However, automated red light cameras are sometimes not practical, feasible or legal in some communities. Confirmation light system, a low-cost engineering countermeasures (both self-enforcing and aiding law enforcement), is another alternative to automated red light cameras in mitigating RLR violations and associated crashes.

This research study evaluated blue confirmation lights at two signalized intersections in the City of Lawrence, Kansas. The two treatment sites were identified by working directly with the City of Lawrence Traffic Engineering Department, and the Lawrence Police Department. In addition to the two treatment intersections, spillover intersections next to the treatment intersections were selected to determine if the confirmation lights have any on RLR violations at nearby intersections. Also, control intersections were identified within the City of Lawrence but were located far from the treatment intersections or the corridor under investigation.

Typical countermeasure effectiveness studies usually rely on three to six years of before and after crash data. Since crash data were limited to this study, a before-after violation study was used as a surrogate measure to evaluate the effectiveness of the blue confirmation lights. This study was completed with the understanding that a decrease or an increase in RLR violations would be equated to a possible decrease or increase RLR crashes based on traffic exposure.

Prior to installation of the confirmation lights in July 2013, field video data were collected at the study sites and considered as the before study period. One month after and three months after installation of the confirmation lights, RLR violation data were collected at the study sites to determine the short-term and long-term effectiveness of the lights. A test of proportion was used to analyze the changes in violation rates from the before period to each after period. Moreover, a Chi Square Test of Independence was also utilized to analyze the RLR violation times into red as a secondary performance matrix to evaluate whether confirmation lights had any effects on driver behavior.

7.1 Summary of Findings

7.1.1 General Conclusions

Right-turn violation by a single vehicle was the most common type of RLR violation in the City of Lawrence. This violation type contributed to approximately half of the RLR violations observed during each study period. The before and one month after study periods showed left-turn RLR violation by a single vehicle as the second most observed violation type followed by a through-movement violation by a single vehicle. However, the three months after study saw more through-movement violation by a single vehicle than left-turn violation by a single vehicle.

Multiple vehicles running red lights either in a platoon or traveling side by side on the left and through lanes accounted for less than two percent of the total observed violations for each study period. The percentage of right-turn violations by multiple vehicles in platoon ranged from three to six percent.

During each study period, more than 98 percent of the RLR violations were committed by drivers of passenger cars. Buses, trucks and recreational vehicles were less involved in the observed RLR violations (accounted for about two percent of the total entering vehicles).

The frequency of the RLR violations was highest in the morning between 7:30 a.m. and 8 a.m. and in the evening between 5 p.m. and 5:30 p.m. for each study period.

7.1.2 Left-turn and Through-movement RLR Violations

In general, the one month after violation study saw a 57.4 percent reduction in the left-turn RLR violation rates at the treatment sites and a 55.7 percent reduction at the spillover sites. Both of these reductions were statistically significant at the 95 percent level of confidence. At the treatment sites, the violation study three months after the installation of the confirmation lights saw a 42.7 percent decrease in RLR violation rates, which was statistically significant, and a 31.7 percent decrease (not statistically significant) at spillover sites. Considering the control sites, there was minimal reduction in left-turn RLR violations, which indicate that confirmation lights had a positive effective in reducing RLR violation in the short and long term periods.These findings are consistent or similar with the study reported by Reddy et al. (2008), where they saw a 25 percent reduction in violations after the implementation of confirmation lights.

The presence of the confirmation lights (installed on left-turning approaches at the treatment sites) had a positive impact on through-movement traffic at treatment and spillover sites in the short term period. One month after installation of the confirmation lights, the treatment sites saw 84.1 percent overall reduction in violations which was statistically significant. However, the three month after study did not see any significant change. The spillover sites saw 14.4 percent overall reductions (not statistically significant) in violations during the one month after study but saw an overall increase (68.8 percent) in violation rates during the three months after study which was statistically significant. At the control sites, the violation rates increased during both one month after study (not statistically significant) and three months after study (statistically significant) periods. Although the treatment intersections did not have confirmation lights installed for the through movement, the lights were effective in the short term for reducing RLR violations.

7.1.3 Left-turn and Through-movement RLR Violations Time into Red

Results of the analysis of the RLR violation time into red showed that most violations occurred less than one second after the onset of the red phase of the signal. This indicated that the violations were most likely intentional. RLR violations more than five seconds after the indication of the red signal indication were also observed at the study intersections. These violations were all early departures, thus, violators initially stopped on red but ran the red light upon waiting for more than five seconds after the red signal was indicated.

The Chi Square Test showed no statistical significant effect (at 95 percent level of confidence) on RLR violation time into red one month after and three months after installation of the confirmation lights. No significant relation was found between RLR violation time into red and the treatment (blue confirmation lights). This means that this countermeasure is less effective in changing driver behavior when a violation occurs.

Overall, the finding of this study showed that confirmation lights when used in combination with normal enforcement can have a positive impact in reducing RLR violations and related crashes at signalized intersections.

7.2 Contributions to Highway Safety

This research study has shown that confirmation lights, when used in combination with target enforcement efforts can provide the intersection safety, efficiency and cost benefits in the following ways:

- Confirmation lights reduce RLR violations which may result in serious crashes. Thereby promoting safety at signalized intersections.
- Confirmation lights are low-cost (cost range between $110 and $140) alternative to automated enforcement. They are also easy to install and maintain.
- Confirmation lights can potentially replace a police officer (located upstream of an intersection observing RLR violations). This will maximize the efficient use of police enforcement resources.
- Confirmation lights have no privacy issues of controversial automated photography.

7.3 Future Research

This study evaluated the effectiveness of confirmation lights at signalized intersections in Lawrence, Kansas after one and three months after installation. It is recommended that

- Crash data analysis should be conducted to evaluate the effectiveness of confirmation lights in reducing RLR crashes if crash data become available.
- Additional violation study one year or more after the installation should be conducted to determine if confirmation lights have long lasting impacts on reducing RLR violations in order to avoid any seasonal changes that may be present in this current research. This study may also be conducted to include off-peak hours if possible.

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APPENDIX A

Characteristics and Aerial Views of Intersections

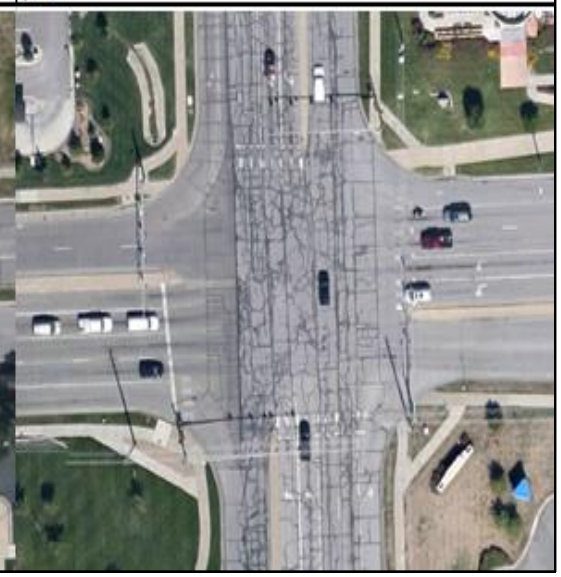
Intersection	6th & Wakarusa	6th & Monterey
Number of Left Turn Lanes (LTL) if present	2 on each approach	1 on each 6th St. approach
Protected Left Turn Lane	Yes	Yes
Protected/Permitted Left Turn Lane	No Permitted	No Permitted
Right Turn Signal (RTS)	Yes	No
Protected Right Turn Signal	Yes	No
Protected/Permitted Right Turn Signal	No Permitted	No
Daily Entering Volume		
Number of Lanes on Approach	5	3 on 6th, 2 on Monterey
Signal Over Each Lane	Yes	Yes
Crosswalks	Yes	Yes, on 6th
Distance to Adjacent Signalized Intersection	1,200 ft	2,000 ft
Flashing Yellow		
Location for Police to Moniter	Yes	Yes
Aerial View of Intersection		

Intersection	6th & Kasold	23rd & Wakarusa
Number of Left Turn Lanes (LTL) if present	2 on 6th, 1 on Kasold	1 on each approach
Protected Left Turn Lane	Yes	Yes
Protected/Permitted Left Turn Lane	No Permitted	No Permitted
Right Turn Signal (RTS)	No	Yes
Protected Right Turn Signal	No	Yes
Protected/Permitted Right Turn Signal	No	No Permitted
Daily Entering Volume		
Number of Lanes on Approach	4 on 6th, 3 on Kasold	4 on 23rd, 3 on Wakarusa
Signal Over Each Lane	Yes	Yes
Crosswalks	Yes	Yes
Distance to Adjacent Signalized Intersection	2,000 ft	2,600 ft
Flashing Yellow		
Location for Police to Moniter	Yes	No
Aerial View of Intersection		

Intersection	23rd & Naismith	23rd & Louisiana
Number of Left Turn Lanes (LTL) if present	1 on each approach	one on each approach
Protected Left Turn Lane	yes	only 2 E/W
Protected/Permitted Left Turn Lane	no	only 2 N/S
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	2 lanes N and 3 on others	3 lanes on each approach
Signal Over Each Lane	3 sig. E/W and 1 sig. N/S	3 sig E/W and 1 sig N/S
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	o.2E/0.3W/0.5N	0.5N/0.3E/0.25W
Flashing Yellow	no	yes
Location for Police to Moniter	yes	yes
Aerial View of Intersection		

Intersection	23rd & Massachusettes	23rd & Harper
Number of Left Turn Lanes (LTL) if present	one lane on each approach	one on each approach
Protected Left Turn Lane	only 2 N/S	yes
Protected/Permitted Left Turn Lane	Only 2 E/W	no
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	3N/2S and 3 E/W	2 N/S and 3 E/W
Signal Over Each Lane	3 sig E/W, 2 sig N and 1 sig S	3 sig on W/E and 1 sig. N/S
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	0.3W/0.15E/0.5N	0.5 W
Flashing Yellow	yes	no
Location for Police to Moniter	no	yes
Aerial View of Intersection		

Intersection	15th & Iowa	15th & Kasold
Number of Left Turn Lanes (LTL) if present	one on each approach	one on each approach
Protected Left Turn Lane	only 2 N/S	only 2 N/S
Protected/Permitted Left Turn Lane	only 2 E/W	only 2 E/W
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	4S and 3 on others	3 lanes on each approach
Signal Over Each Lane	3 sig. on N/S 2 sig. on E/W	3 sig. on N/S 2 sig. on E/W
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	0.5S/0.35W/0.5N	0.65E/0.5W/1N/0.88S
Flashing Yellow	yes	yes
Location for Police to Moniter	yes	yes
Aerial View of Intersection		

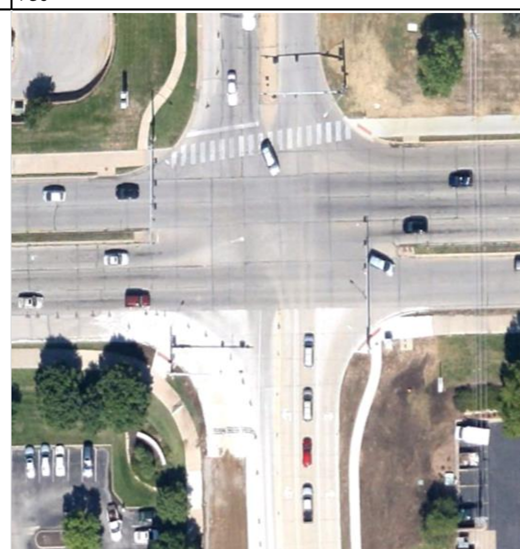
Intersection	15th & Wakarusa	31st & Iowa
Number of Left Turn Lanes (LTL) if present	one on each approach	one on each approach
Protected Left Turn Lane	no	no
Protected/Permitted Left Turn Lane	yes	yes
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	3 lanes on each approach	2N, 3S/E/W
Signal Over Each Lane	2 signals on each lane	2 sig. N/S 3 sig. on W/E
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	1 N/S/E	0.3W
Flashing Yellow	yes	yes
Location for Police to Moniter	yes	yes
Aerial View of Intersection		

Intersection	31st & Ousdahl	Kasold & Peterson
Number of Left Turn Lanes (LTL) if present	2 on each approach	one on each approach
Protected Left Turn Lane	yes	no
Protected/Permitted Left Turn Lane	no	yes
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	5 lanes on each approach	4N/4S/2E/3W
Signal Over Each Lane	4 signals on each approach	2 signals on each approach
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	0.43N/0.25S/0.1W	1 mile south
Flashing Yellow	no	yes
Location for Police to Moniter	yes	no
Aerial View of Intersection		

Intersection	2nd & McDonald	9th & Iowa
Number of Left Turn Lanes (LTL) if present	one on each approach	one on each approach
Protected Left Turn Lane	no	only 2 N/S
Protected/Permitted Left Turn Lane	yes	only 2 E/W
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	4N/2S/3E/2W	4N/2W/3S/3E
Signal Over Each Lane	2 sig. on N & 1 on others	3 sig. N/S, 2 sig. W/E
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	no adjacent sig. int.	0.5N/0.5S/0.5E
Flashing Yellow	yes	yes
Location for Police to Moniter	yes	yes
Aerial View of Intersection		

Intersection	19th & Naismith	19th & Louisiana
Number of Left Turn Lanes (LTL) if present	one on each approach	one on each approach
Protected Left Turn Lane	no	only 2 E/W
Protected/Permitted Left Turn Lane	yes	only 2 N/S
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	3N/2W/3S/2E	2N/3S/2E/3W lanes
Signal Over Each Lane	2 sig. N/S, 1 sig E/W	2 signals on each approach
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	0.5W/0.5E/0.5S	0.13E/0.5W/0.5S
Flashing Yellow	yes	yes
Location for Police to Moniter	yes	yes
Aerial View of Intersection		

Intersection	19th & Massachusetts	19th & Haskell
Number of Left Turn Lanes (LTL) if present	one on each approach	one on each approach
Protected Left Turn Lane	no	no
Protected/Permitted Left Turn Lane	yes	yes
Right Turn Signal (RTS)	no	no
Protected Right Turn Signal	no	no
Protected/Permitted Right Turn Signal	no	no
Daily Entering Volume		
Number of Lanes on Approach	3 lanes E/W and 2 lanes N/S	2 lanes
Signal Over Each Lane	singnal on each lane	1 signal on each approach
Crosswalks	yes	yes
Distance to Adjacent Signalized Intersection	0.12W/0.24N/0.5S/	0.19W/0.25E
Flashing Yellow	yes	no
Location for Police to Moniter	yes	yes
Aerial View of Intersection		

Intersection	23rd & Kasold	23rd & Iowa
Number of Left Turn Lanes (LTL) if present	1 on each approach	2 each N/S and 1 each W/E
Protected Left Turn Lane	Yes	Yes
Protected/Permitted Left Turn Lane	No Permitted	No Permitted
Right Turn Signal (RTS)	Yes	No
Protected Right Turn Signal	Yes	No
Protected/Permitted Right Turn Signal	No Permitted	No
Daily Entering Volume		
Number of Lanes on Approach	4 on 23rd, 3 on Kasold	5 lanes N/S and 4 lanes E/W
Signal Over Each Lane	Yes	3 signals on each approach
Crosswalks	Yes	Yes
Distance to Adjacent Signalized Intersection	1,200 ft	0.25E/0.5N/0.3S/0.25W
Flashing Yellow	Yes	No
Location for Police to Moniter	Yes	Yes
Aerial View of Intersection		

APPENDIX B

Reduced RLR Violation Data for Before and After Studies

BEFORE STUDY RLR VIOLATIONS

Treatment Sites

Before Study at Intersection of 23rd Street & Louisiana Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2			1		7:27
2	1	1			1		7:51
3	1	1				2	8:53
4	1	1				2	8:55
5	1	4	3				7:13
6	1	4	3				7:26
7	1	1	3				7:57
8	1	1	3				8:19
9	1	94	3				8:26
10	1	1	3				8:32
11	1	30		3			7:05
12	1	49		3			7:27
13	1	34		3			8:22

Before Study at 23rd Street & Louisiana Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (PM)
1	1	1			1		4:41
2	1	2			1		4:57
3	1	1			1		5:23
4	1	13			3		5:57
5	1	1				1	4:54
6	1	2				3	5:20
7	1	1				1	5:57
8	1	1		2			4:30
9	1	1		3			4:58
10	1	1		3			5:20
11	1	1		3			5:29
12	1	1	1				4:31
13	1	1	1				5:25
14	1	1	3				5:27
15	1	1	3				5:47

Before Study 23rd Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2		1			7:47
2	1	2		1			8:10
3	1	2		1			8:12
4	1	2		1			8:22
5	1	1		1			8:29
6	1	1		1			8:32
7	1	1		1			8:48
8	1	1			1		7:05
9	1	31			3		7:50
10	1	33			3		8:22
11	1	28			3		8:26
12	1	38			3		8:28
13	1	1			1		8:30
14	1	35			3		8:33
15	1	18			3		8:35
16	1	1			2		8:36
17	1	37			3		8:44
18	1	1			2		8:46
19	1	1			3		8:46
20	1	37			3		8:46
21	1	42			3		8:47
22	1	1			1		8:48
23	1	2			2		8:53

Before Study at 23rd Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1				2	5:19
2	1	2				1	5:33
3	1	1				2	5:47
4	1	1				1	5:59
5	1	1				2	6:15
6	1	2		1			4:37
7	1	1		1			4:42
8	1	1		7			4:44
9	1	1		7			4:44
10	1	3		1			5:02
11	1	1		1			5:04
12	1	1		1			5:06
13	1	2		1			5:10
14	1	1		7			5:25
15	1	1		7			5:25
16	1	1		1			5:32
17	1	1		2			6:07
18	1	1		2			6:22
19	1	3		1			6:29
20	1	1			1		4:48
21	1	1			3		4:55
22	1	1			3		5:01
23	1	2			1		5:08
24	1	3			3		5:10
25	1	1			1		5:13
26	1	1			2		5:14
27	1	8			3		5:33
28	1	1			2		6:06
29	1	43			3		6:34
30	1	1	7				4:48
31	1	1	7				4:48
32	1	2	1				5:40
33	1	1	2				5:43
34	1	2	1				5:46
35	1	1	7				6:20
36	1	1	7				6:20

Before Study Traffic Volume at Treatment Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
23rd Street & Iowa Street	Morning Peak	NB	148	1,148	0	1,296
		SB	445	654	0	1,099
		WB	183	845	0	1,028
		EB	501	1,280	149	1,930
		Total	**1,277**	**3,927**	**149**	**5,353**
	Evening Peak	NB	336	1,375	-	1,711
		SB	621	1,516	-	2,137
		WB	405	1,515	-	1,920
		EB	393	1,153	283	1,829
		Total	**1,755**	**5,559**	**283**	**7,597**
23rd Street & Louisiana Street	Morning Peak	NB	139	414	258	811
		SB	136	244	200	580
		WB	133	1,454	199	1,786
		EB	236	1,559	83	1,878
		Total	**644**	**3,671**	**740**	**5,055**
	Evening Peak	NB	248	499	357	1,104
		SB	212	584	243	1,039
		WB	434	1,899	113	2,446
		EB	278	1,823	129	2,230
		Total	**1,172**	**4,805**	**842**	**6,819**

Control Sites

Before Study at 31st Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1			2		7:14
2	1	1			3		7:27
3	1	1			3		7:41
4	1	33			3		8:03
5	1	19			3		8:04
6	1	14				3	8:09
7	1	1				3	8:15
8	1	65				3	8:28
9	1	41				6	8:32
10	1	43				6	8:32
11	1	5				3	8:52
12	1	20				3	8:59
13	1	15		3			8:46
14	1	33		3			8:48
15	1	16	3				8:05
16	1	2	3				8:34

Before Study at 31st Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	56			3		5:56
2	1	35			3		6:12
3	1	1			3		6:16
4	1	2		3			5:14
5	1	53	3				4:47
6	1	3				3	4:36
7	1	2				3	5:16
8	1	22				3	5:42

Before Study at 6th Street & Wakarusa Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	36			3		7:36
2	1	49			3		7:40
3	1	1			3		7:49
4	1	6			3		8:04
5	1	23			3		8:08
6	1	50			3		8:08
7	1	1			2		8:13
8	1	17			3		8:15
9	1	1			3		8:38
10	1	2			3		8:42
11	1	37			3		8:44
12	1	1			3		8:52
13	1	8				1	7:06
14	1	1				2	7:10
15	1	2				3	7:17
16	1	1				1	7:48
17	1	1				3	8:16
18	1	28				6	8:20
19	1	29				6	8:20
20	1	34				3	8:55
21	1	19	3				7:28
22	1	1	3				7:32
23	1	1	3				7:39
24	1	2	3				8:01
25	1	2	3				8:06
26	1	30	3				8:16
27	1	1	3				8:18
28	1	3	3				8:40
29	1	23	3				8;46
30	2	6	3				8:50
31	1	8	3				8:56

Before Study at 6th Street & Wakarusa Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	5			3		4:02
2	1	32			3		4:04
3	1	1			2		4:10
4	1	3			3		4:31
5	1	27			3		5:30
6	1	26				3	4:01
7	1	1				2	4:08
8	1	1				1	4:09
9	1	59				3	4:40
10	1	1				3	5:05
11	1	1				3	5:28
12	1	60				3	5:44
13	1	30	3				4:01
14	1	34	3				4:24
15	1	2	3				4:25
16	1	4	3				4:27
17	1	1	3				4:57
`18	1	2	3				5:00
19	1	2	3				5:20
20	1	5	3				5:33

Before Study at Clinton Parkway & Kasold Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	40			1		7:19
2	1	51			3		7:53
3	1	4			3		7:57
4	1	2			3		8:28
5	1	18				3	7:12
6	1	46				3	7:15
7	1	1				1	7:21
8	1	33				3	7:27
9	1	32				3	7:33
10	1	18				3	7:37
11	1	44				3	7:37
12	1	1				1	7:57
13	1	38				3	8:22
14	1	1				1	8:25
15	1	83				1	8:33
16	1	5	3				7:09
17	1	9	3				7:11
18	1	12	3				7:45
19	1	17	3				7:47
20	1	1	2				8:02
21	1	11	3				8:02
22	1	20	3				8:03
23	1	15	3				8:15
24	1	3	3				8:30
25	1	14	3				8:40
26	1	35	3				8:51
27	1	21		3			7:13
28	1	18		3			7:31
29	1	14		3			7:47
30	1	1		3			7:53
31	1	12		3			8:53

Before Study at Clinton Parkway & Kasold Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	41			3		4:32
2	1	1			2		4:36
3	1	3			3		4:48
4	1	1				3	4:01
5	1	1				3	4:15
6	1	1				2	4:25
7	1	1				1	5:09
8	1	1				3	5:26
9	1	1				1	5:46
10	1	2				1	5:54
11	1	1				1	5:58
12	1	2	3				4:15
13	1	9	3				4:15
14	1	12		3			4:16
15	1	5		3			4:18
16	1	2		1			4:42
17	1	9		3			5:03
18	1	1		1			5:23
19	1	11		3			5:49

Before Study at 6th Street & Kasold Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1		3			7:28
2	1	5		3			8:14
3	1	1		3			8:32
4	1	39		3			8:36
5	1	3				3	7:37
6	1	13	3				7:17
7	1	15	3				7:19
8	1	6	3				7:57
9	1	11			3		7:55
10	1	3			3		8:41

Before Study at 6th Street & Kasold Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	7			3		4:06
2	1	10			3		4:41
3	1	1			2		5:01
4	1	19			3		5:03
5	1	21			3		5:11
6	1	1			2		5:13
7	1	15			3		5:15
8	1	5			3		5:39
9	1	1				1	4:04
10	1	2				1	4:37
11	1	1				2	5:21
12	1	3				3	5:54
13	1	12		3			5:32
14	1	5	3				4:03
15	1	12	3				4:03
16	1	8	3				4:13
17	1	13	3				4:13
18	1	14	3				4:21
19	1	52	3				4:33
20	1	10	3				4:37
21	1	16	3				4:45
22	1	14	3				4:47
23	1	10	3				4:49
24	1	10	6				5:08
25	1	14	6				5:08
26	1	16	6				5:08
27	1	20	6				5:08
28	1	1	1				5:15
29	2	58	3				5:29
30	1	1	3				5:32
31	1	14	3				5:32
32	1	2	3				5:34
33	1	1	3				5:48
34	1	18	3				5:48

Before Study at 6th Street & Michigan Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1			2		8:15
2	1	1			2		8:17
3	1	5				3	7:02
4	1	20				3	7:16
5	1	16				3	7:40
6	1	39				3	8:18
7	1	35				3	8:46
8	1	4				3	8:48
9	1	13				3	8:58
10	1	1		1			7:31

Before Study at 6th Street & Michigan Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1				2	4:14
2	1	10				3	5:08
3	1	1			2		4:01
4	2	4			1		4:36
5	1	3			1		5:15
6	1	3			1		5:19
7	1	1			1		5:41

Before Study Traffic Volume at Control Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
6th Street & Kasold Drive	Morning Peak	NB	232	186	337	755
		SB	218	336	93	647
		WB	200	1,026	58	1,284
		EB	39	1,579	229	1,847
		Total	**689**	**3,127**	**717**	**4,533**
	Evening Peak	NB	495	358	349	1,202
		SB	174	361	120	655
		WB	420	1,955	139	2,514
		EB	118	1,609	346	2,073
		Total	**1,207**	**4,283**	**954**	**6,444**
6th Street & Michigan Street	Morning Peak	NB	68	78	18	164
		SB	411	86	71	568
		WB	13	216	1348	1577
		EB	65	1733	32	1830
		Total	**557**	**2113**	**1469**	**4139**
	Evening Peak	NB	123	101	20	244
		SB	403	65	215	683
		WB	19	2,243	220	2,482
		EB	69	1,841	53	1,963
		Total	**614**	**4,250**	**508**	**5,372**
31st Street & Iowa Street	Morning Peak	NB	95	916	220	1,231
		SB	115	442	171	728
		WB	138	300	208	646
		EB	206	402	108	716
		Total	**554**	**2,060**	**707**	**3,321**
	Evening Peak	NB	251	923	187	1,361
		SB	376	1,092	358	1,826
		WB	249	488	261	998
		EB	395	514	253	1,162
		Total	**1,271**	**3,017**	**1,059**	**5,347**
6th Street & Wakarusa Drive	Morning Peak	NB	325	260	404	989
		SB	145	235	63	443
		WB	493	552	66	1,111
		EB	46	643	214	903
		Total	**1,009**	**1,690**	**747**	**3,446**
	Evening Peak	NB	318	316	627	1,261
		SB	227	311	66	604
		WB	633	752	206	1,591
		EB	56	868	235	1,159
		Total	**1,234**	**2,247**	**1,134**	**4,615**
Clinton Parkway & Kasold Drive	Morning Peak	NB	146	371	197	714
		SB	428	315	98	841
		WB	125	791	355	1,271
		EB	169	1394	185	1,748
		Total	**868**	**2,871**	**835**	**4,574**
	Evening Peak	NB	275	606	201	1,082
		SB	582	643	223	1,448
		WB	262	1,465	643	2,370
		EB	137	1,118	301	1,556
		Total	**1,256**	**3,832**	**1,368**	**6,456**

Spillover Sites

Before Study at 19th Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2	3				7:35
2	1	1	3				7:45
3	1	12	3				8:25
4	1	3	3				8:32
5	1	1	3				8:47
6	1	2	3				8:49
7	1	2	6				8:55
8	1	15	6				8:55
9	1	17	6				8:55
10	2	19		1			7:01
11	1	60		1			7:23
12	1	1		2			7:27
13	1	3		1			7:31
14	1	2		1			7:41
15	1	1		1			7:44
16	1	1		1			7:54
17	1	1		1			8:29
18	1	1		2			8:41
19	1	1		1			8:44
20	1	2		1			8:53
21	1	6		3			9:04
22	1	2			2		7:38
23	1	44			3		8:00
24	1	1				3	7:14
25	1	3				3	7:32
26	1	3				3	7:43
27	1	3				3	8:00
28	1	3				3	8:29
29	1	60				3	8:38

Before Study at 19 Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	6	3				4:48
2	1	2	3				4:51
3	1	8	6				5:06
4	1	13	6				5:06
5	1	3	2				5:11
6	1	1	2				5:21
7	1	1	2				5:26
8	1	1	3				5:27
9	1	3	3				5:32
10	1	1	3				5:36
11	1	12	6				5:41
12	1	15	6				5:41
13	1	10	3				6:04
14	1	13	3				6:13
15	1	4	6				6:27
16	1	7	6				6:27
17	1	10	6				6:27
18	1	2		1			4:46
19	1	1		1			4:49
20	1	2		3			4:50
21	1	2		1			4:52
22	1	2		1			4:59
23	1	2		1			5:20
24	1	1		1			5:48
25	1	2		2			5:53
26	1	2		4			5:57
27	1	3		4			5:57
28	1	2		1			6:00
29	1	1		2			6:13
30	1	1		2			6:19
31	1	2				3	4:35
32	1	2				3	4:52
33	1	3				4	5:20
34	1	4				4	5:20
35	1	5				3	5:33
36	1	2				3	5:35
37	1	2				3	5:38
38	1	1				3	5:40
39	1	2				3	6:15
40	1	2				3	6:37
41	1	8			3		5:00
42	1	102			3		5:30
43	1	10			6		5:40
44	1	11			6		5:40
45	1	13			6		5:45
46	1	14			6		5:45
47	1	191			3		6:18

Before Study at 19th Street & Louisiana (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	22			3		7:06
2	1	1				1	7:39
3	1	257		3			7:40
4	1	84		3			7:47
5	1	2	3				7:00
6	1	8	3				7:11
7	1	1	1				8:35

Before Study at 19th Street & Louisiana (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	2			3		4:26
2	1	6			3		5:48
3	1	1				1	4:55
4	1	1				1	5:10
5	1	56	3				5:06

Before Study at 23rd Street & Ousdahl (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1			2		7:49
2	1	1			1		7:53
3	1	1				2	7:22
4	1	77		3			7:17
5	1	83		3			7:44
6	1	1		2			7:52
7	1	21		3			7:55
8	1	10		3			8:00
9	1	1	1				7:42

Before Study at 23rd Street & Ousdahl (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	2			3		5:12
2	1	1				3	5:03
3	1	1				3	5:38
4	1	1	1				5:35
5	1	3		3			5:29
6	1	1		3			5:56

Before Study at 25th Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (AM)
1	1	13		3			7:54

Before Study at 25th Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		5:20
2	1	1			1		5:22
3	1	3				3	5:27
4	1	1	2				5:37
5	1	1	2				6:27
6	1	1	2				6:29
7	1	2		2			4:45
8	1	1		2			5:16
9	1	1		2			5:28
10	1	1		2			6:28

Before Study at Crestline Drive & Clinton Parkway (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2			3		7:00
2	1	9			3		8:27
3	1	1			2		8:43
4	1	1				2	7:02
5	1	4				3	7:29
6	1	57	3				7:09
7	1	68	3				7:09
8	1	4	3				8:16
9	1	56	3				8:43
10	1	60		3			7:01
11	1	87		3			7:27
12	1	79		3			7:43
13	1	77		3			9:00

Before Study at Crestline Drive & Clinton Parkway (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		4:12
2	1	1			3		5:26
3	1	5				3	5:04
4	1	1				2	5:14
5	1	2				1	5:24
6	1	2				2	5:54
7	1	3	3				5:39
8	1	23		3			4:36
9	1	45		3			4:37

Before Study at 23rd Street & Alabama Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1		2			8:00
2	1	10	3				7:32
3	1	1				2	7:18
4	1	4				3	7:22
5	1	1				2	8:28
6	1	1				2	8:39
7	1	1			1		7:36
8	1	5			3		8:37

Before Study at 23rd Street & Alabama Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		5:19
2	1	7	3				5:14
3	1	2	3				5:29

Before Study Traffic Volume at Spillover Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
23rd Street & Ousdahl Street	Morning Peak	NB	34	69	30	133
		SB	56	161	71	288
		WB	42	1,552	68	1,662
		EB	246	1,878	37	2,161
		Total	**378**	**3,660**	**206**	**4,244**
	Evening Peak	NB	123	91	78	292
		SB	84	145	187	416
		WB	102	2,107	93	2,302
		EB	136	2,124	95	2,355
		Total	**445**	**4,467**	**453**	**5,365**
19th Street & Iowa Street	Morning Peak	NB	32	1,655	386	2,073
		SB	478	1,325	112	1,915
		WB	186	108	484	778
		EB	15	133	30	178
		Total	**711**	**3,221**	**1,012**	**4,944**
	Evening Peak	NB	71	1,894	313	2,278
		SB	475	2,352	28	2,855
		WB	513	109	548	1,170
		EB	73	160	129	362
		Total	**1,132**	**4,515**	**1,018**	**6,665**
19th Street & Louisiana Street	Morning Peak	NB	323	86	293	702
		SB	24	46	31	101
		WB	285	833	23	1,141
		EB	13	553	148	714
		Total	**645**	**1,518**	**495**	**2,658**
	Evening Peak	NB	139	447	100	686
		SB	87	153	21	261
		WB	542	1,001	17	1,560
		EB	26	806	206	1,038
		Total	**794**	**2,407**	**344**	**3,545**
Clinton Parkway & Crestline Drive	Morning Peak	NB	107	18	172	297
		SB	8	4	33	45
		WB	122	1,196	142	1,460
		EB	279	2,098	239	2,616
		Total	**516**	**3,316**	**586**	**4,418**
	Evening Peak	NB	142	6	56	204
		SB	163	12	204	379
		WB	59	1,659	31	1,749
		EB	53	1,800	116	1,969
		Total	**417**	**3,477**	**407**	**4,301**

Before Study Traffic Volume at Spillover Sites (continued)

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
25th Street & Iowa Street	Morning Peak	NB	34	1,467	24	1,525
		SB	24	762	65	851
		WB	20	17	37	74
		EB	85	32	36	153
		Total	**163**	**2,278**	**162**	**2,603**
	Evening Peak	NB	82	2,136	44	2,262
		SB	67	1,984	98	2,149
		WB	94	68	49	211
		EB	147	46	53	246
		Total	**390**	**4,234**	**244**	**4,868**
23rd Street & Alabama Street	Morning Peak	NB	112	84	176	372
		SB	18	29	29	76
		WB	49	1,570	14	1,633
		EB	59	1,637	63	1,759
		Total	**238**	**3,320**	**282**	**3,840**
	Evening Peak	NB	177	62	113	352
		SB	62	98	62	222
		WB	147	2,404	51	2,602
		EB	78	2,299	159	2,536
		Total	**464**	**4,863**	**385**	**5,712**

1 MONTH AFTER STUDY RLR VIOLATIONS

Treatment Sites

1 Month after Study at 23rd Street & Louisiana Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1			1		7:52
2	1	1			3		8:08
3	1	1	3				8:14
4	1	1		3			7:20
5	1	4		3			7:57

1 Month after Study at 23rd Street & Louisiana Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	3			2		4:46
2	1	1				3	4:16
3	1	1				1	4:20
4	1	1				1	4:59
5	1	1				1	5:02
6	1	1	1				4:02
7	1	84	3				4:06
8	1	1	3				5:10
9	1	1	1				5:49
10	1	1		3			5:06

1 Month after Study at 23rd Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2			3		7:54
2	1	2			3		8:03
3	1	2				2	7:54
4	1	1		1			7:43
5	1	1		1			8:03
6	1	4		1			8:49
7	1	2		1			8:53

1 Month after Study at 23rd Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	3			3		4:20
2	1	1			6		4:26
3	1	3			6		4:26
4	1	6			3		4:35
5	1	2			6		4:43
6	1	4			6		4:43
7	1	7			6		4:44
8	1	3			3		4:47
9	1	36			3		5:37
10	1	1				1	5:12
11	1	1				1	5:37
12	1	1	1				4:17
13	1	1		1			4:21
14	1	1		1			4:39
15	1	1		1			4:51
16	1	1		1			5:51

1 Month after Study Traffic Volume at Treatment Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
23rd Street & Iowa Street	Morning Peak	NB	101	785	-	886
		SB	303	544	-	847
		WB	182	751	-	933
		EB	379	1,132	131	1,642
		Total	**965**	**3,212**	**131**	**4,308**
	Evening Peak	NB	265	908	-	1,173
		SB	525	1,076	-	1,601
		WB	471	1,477	-	1,948
		EB	265	1,120	261	1,646
		Total	**1,526**	**4,581**	**261**	**6,368**
23rd Street & Louisiana Street	Morning Peak	NB	147	439	306	892
		SB	112	264	146	522
		WB	207	1,379	183	1,769
		EB	214	1,790	92	2,096
		Total	**680**	**3,872**	**727**	**5,279**
	Evening Peak	NB	233	478	368	1,079
		SB	193	611	232	1,036
		WB	410	1,615	59	2,084
		EB	226	1,748	164	2,138
		Total	**1,062**	**4,452**	**823**	**6,337**

Control Sites

1 Month after Study at 6th Street & Kasold Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	11			3		7:12
2	1	1			2		7:20
3	1	1			3		7:42
4	1	1			3		8:00
5	1	1			2		8:02
6	1	3			3		8:02
7	1	4			1		8:05
8	1	1			2		8:08
9	1	13			3		8:18
10	1	14			3		8:48
11	1	52		3			7:09
12	1	2		1			8:24
13	1	2		3			8:55
14	1	10	3				7:03
15	1	9	3				7:23
16	1	52	3				7:34
17	1	19	3				7:59
18	1	13	3				8:21
19	1	35	3				8:32
20	1	16	3				8:49
21	1	1				1	7:31
22	1	1				1	7:33
23	1	2				1	8:18
24	1	3				3	8:56

1 Month after Study at 6th Street & Kasold Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	2		1			4:31
2	1	64	3				4:11
3	1	53	3				4:31
4	1	11	3				4:42
5	1	18	3				4:46
6	1	14	3				5:18
7	1	10	3				5:42
8	1	10			3		4:24
9	1	42			3		4:59
10	1	16			3		5:04
11	1	45			3		5:11
12	1	1			2		5:12
13	1	1			2		5:14
14	1	41			3		5:25
15	1	4			3		5:42
16	1	3				1	4:57
17	1	1				1	5:03
18	1	1				2	5:03
19	2	2				2	5:33

1 Month after Study at 31st Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	71			3		7:05
2	1	150			3		7:20
3	1	72			3		7:37
4	1	52			3		8:08
5	1	79				3	8:35
6	1	13	3				7:07
7	1	13		3			7:39
8	1	37		3			7:43

1 Month after Study at 31st Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			3		5:22
2	1	1				1	5:37
3	1	37				3	5:51
4	1	46	3				4:44
5	1	43	3				4:49

1 Month after Study at 6th Street & Michigan Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1				2	7:37
2	1	3				3	7:37
3	1	5				3	8:19
4	1	2				3	8:21
5	1	1			2		8:10

1 Month after Study at 6th Street & Michigan Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1				1	4:32
2	1	1				2	4:36
3	1	1				2	5:42

1 Month after Study at 6th Street & Wakarusa Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2			2		7:42
2	1	2				2	7:29
3	1	1				2	7:40
4	1	2				3	7:42
5	1	81				3	8:25
6	1	34				3	8:48
7	1	2	3				8:25
8	1	1		1			7:49

1 Month after Study at 6th Street & Wakarusa Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		4:58
2	1	1				2	5:53

1 Month after Study at Clinton Parkway & Kasold Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1				3	7:26
2	1	1				3	7:44
3	1	1				1	8:09
4	1	1			2		7:50
5	1	1	1				8:07
6	1	1		1			7:52

1 Month after Study at Clinton Parkway & Kasold Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	2			1		5:13
2	1	67			3		5:21
3	1	2			1		5:53
4	1	1				2	4:00
5	1	1				1	4:17
6	1	1				1	4:44
7	1	1				1	4:46
8	1	1				1	4:54
9	1	1				1	5:00
10	1	1				4	5:10
11	1	1				4	5:10
12	1	1				1	5:44
13	1	1	1				4:13
14	1	1	1				5:32
15	1	1		1			5:45

1 Month after Study Traffic Volume at Control Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
6th Street & Kasold Drive	Morning Peak	NB	301	208	502	1,011
		SB	212	351	75	638
		WB	266	1,131	87	1,484
		EB	57	1,732	303	2,092
		Total	**836**	**3,422**	**967**	**5,225**
	Evening Peak	NB	564	385	411	1,360
		SB	153	348	95	596
		WB	514	1,988	136	2,638
		EB	110	1,473	351	1,934
		Total	**1,341**	**4,194**	**993**	**6,528**
6st Street & Michigan Street	Morning Peak	NB	85	66	20	171
		SB	402	47	81	530
		WB	4	1,250	126	1,380
		EB	51	1,698	36	1,785
		Total	**542**	**3,061**	**263**	**3,866**
	Evening Peak	NB	109	106	18	233
		SB	409	48	190	647
		WB	19	1,908	191	2,118
		EB	52	1,698	60	1,810
		Total	**589**	**3,760**	**459**	**4,808**
31st Street & Iowa Street	Morning Peak	NB	92	669	141	902
		SB	100	347	149	596
		WB	103	268	112	483
		EB	150	304	105	559
		Total	**445**	**1,588**	**507**	**2,540**
	Evening Peak	NB	239	819	194	1,252
		SB	324	880	269	1,473
		WB	224	491	228	943
		EB	351	571	304	1,226
		Total	**1,138**	**2,761**	**995**	**4,894**
6th Street & Wakarusa Drive	Morning Peak	NB	233	150	372	755
		SB	184	185	70	439
		WB	425	584	105	1,114
		EB	64	826	176	1,066
		Total	**906**	**1,745**	**723**	**3,374**
	Evening Peak	NB	253	189	439	881
		SB	264	164	66	494
		WB	500	821	247	1,568
		EB	66	843	176	1,085
		Total	**1,083**	**2,017**	**928**	**4,028**
Clinton Parkway & Kasold Drive	Morning Peak	NB	103	413	187	703
		SB	546	429	114	1,089
		WB	117	638	447	1,202
		EB	159	922	153	1,234
		Total	**925**	**2,402**	**901**	**4,228**
	Evening Peak	NB	288	1,365	790	2,443
		SB	729	736	224	1,689
		WB	227	1,250	931	2,408
		EB	163	969	238	1,370
		Total	**1,407**	**4,320**	**2,183**	**7,910**

Spillover Sites

1 Month after Study at 23rd Street & Alabama Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	2	1			2		7:54
2	1	63	3				7:30
3	1	73	3				7:34
4	1	87	3				7:37
5	1	87	3				7:37
6	1	65	3				7:54
7	1	1	3				7:59
8	1	70	3				8:02
9	1	50	3				8:14
10	1	19	3				8:22
11	1	2	3				8:33
12	1	1				2	7:24
13	1	1				2	7:24
14	1	1				2	7:38
15	1	1				2	7:56
16	1	1				2	8:26
17	1	2				3	8:40
18	1	3				2	8:42
19	1	28		3			7:17
20	1	56		3			7:41
21	1	57		3			8:37

1 Month after Study at 23rd Street & Alabama Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		4:09
2	1	1			2		4:12
3	1	1			2		4:57
4	1	1			2		5:12
5	1	1	3				4:33
6	1	11	3				5:13
7	1	7	3				5:25
8	1	33	3				5:43
9	1	12	3				5:50
10	1	25	3				5:53
11	1	61	3				5:54
12	1	1				2	5:56
13	1	10		3			5:00
14	1	78		3			5:16

1 Month after Study at 19th Street & Louisiana Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1				1	7:33
2	1	28			3		7:15
3	1	17			3		7:29
4	1	36			3		7:29
5	1	31			3		7:42
6	2	30			3		7:55
7	1	27			3		8:47
8	1	1	3				7:13
9	1	29	3				7:14
10	1	10	3				8:08

1 Month after Study at 19th Street & Louisiana Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	26	3				4:10
2	1	15	3				4:22
3	1	3	3				5:20
4	1	2	3				5:30
5	1	1	3				5:45
6	1	1	3				5:48
7	1	1				1	4:36
8	2	1				1	5:09
9	1	20			3		4:04
10	1	26			3		4:06
11	1	20			3		4:32
12	1	9			3		4:42
13	1	13			3		5:05
14	1	41			3		5:10
15	1	23			3		5:31
16	1	17			3		5:41

1 Month after Study at 25th Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2		2			7:40
2	1	1		2			8:34
3	1	1		2			8:40
4	1	1		3			8:57
5	1	1		3			8:59

1 Month after Study at 25th Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	36			1		4:10
2	1	3			3		4:12
3	1	2			3		5:02
4	1	2				3	4:53

1 Month after Study at 19th Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	42				3	7:39
2	1	20				3	8:10
3	1	21				3	8:38
4	1	15	3				7:21
5	1	2	3				7:56
6	1	1		1			7:07
7	1	2		1			8:07
8	1	16		1			8:21

1 Month after Study at 19th Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	53			3		4:45
2	1	66			3		5:07
3	1	16			3		5:16
4	1	91			3		5:19
5	1	20				3	5:02
6	1	12				3	5:07
7	1	18				3	5:22
8	1	14				3	5:27
9	1	18				6	5:33
10	1	25				6	5:33
11	1	12				3	5:47
12	1	1	1				4:24
13	1	1	2				4:26
14	1	21	3				4:26
15	1	3	3				4:29
16	1	46	1				5:37
17	1	2	2				5:42

1 Month after Study at 23rd Street & Ousdahl Road (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1	1				7:21

1 Month after Study at 23rd Street & Ousdahl Road (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			3		4:55
2	1	106	3				4:11
3	1	45	3				5:13
4	1	1		3			4:07
5	1	12		3			5:49
6	1	1				2	4:40

1 Month after Study at Clinton Parkway & Crestline Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2			2		7:25
2	1	1			3		8:58
3	1	14				3	8:34
4	1	120	3				7:58
5	1	29	3				8:14

1 Month after Study at Clinton Parkway & Crestline Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	13			3		4:09
2	1	8				3	4:38
3	1	5				3	4:56
4	1	10	3				4:53
5	1	54	3				4:55

1 Month after Study Traffic Volume at Spillover Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
23rd Street & Ousdahl Road	Morning Peak	NB	34	18	27	79
		SB	27	18	67	112
		WB	51	1,349	55	191
		EB	94	1,637	48	1,779
		Total	**206**	**3,022**	**197**	**3,425**
	Evening Peak	NB	130	71	72	273
		SB	54	109	160	323
		WB	106	2,409	79	596
		EB	163	2,083	98	2,344
		Total	**453**	**4,672**	**409**	**5,534**
19th Street & Iowa Street	Morning Peak	NB	55	1,142	258	1,455
		SB	127	856	35	1,018
		WB	143	130	173	446
		EB	11	104	76	191
		Total	**336**	**2,232**	**542**	**3,110**
	Evening Peak	NB	95	1,281	194	1,570
		SB	157	1,579	9	1,745
		WB	481	156	185	822
		EB	31	168	134	333
		Total	**764**	**3,184**	**522**	**4,470**
19th Street & Louisiana Street	Morning Peak	NB	245	81	309	635
		SB	16	44	20	80
		WB	314	749	18	1,081
		EB	4	504	186	694
		Total	**579**	**1,378**	**533**	**2,490**
	Evening Peak	NB	132	108	575	815
		SB	83	168	28	279
		WB	614	991	14	1,619
		EB	37	882	190	1,109
		Total	**866**	**2,149**	**807**	**3,822**
Clinton Parkway & Crestline Drive	Morning Peak	NB	55	7	61	123
		SB	6	3	13	22
		WB	24	951	18	993
		EB	140	1,579	75	1,794
		Total	**225**	**2,540**	**167**	**2,932**
	Evening Peak	NB	115	8	58	181
		SB	30	18	168	216
		WB	85	2,087	6	2,178
		EB	14	1,568	102	1,684
		Total	**244**	**3,681**	**334**	**4,259**

1 Month after Study Traffic Volume at Spillover Sites (Continuation)

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
25th Street & Iowa Street	Morning Peak	NB	22	979	16	1,017
		SB	25	675	42	742
		WB	29	8	40	77
		EB	53	16	22	91
		Total	**129**	**1,678**	**120**	**1,927**
	Evening Peak	NB	72	1,291	44	1,407
		SB	43	1,451	69	1,563
		WB	76	61	48	185
		EB	141	49	60	250
		Total	**332**	**2,852**	**221**	**3,405**
23rd Street & Alabama Street	Morning Peak	NB	117	38	157	312
		SB	9	15	11	35
		WB	51	1,564	11	1,626
		EB	31	1,719	68	1,818
		Total	**208**	**3,336**	**247**	**3,791**
	Evening Peak	NB	147	37	118	302
		SB	38	74	44	156
		WB	143	2,408	26	2,577
		EB	75	132	2,249	2,456
		Total	**403**	**2,651**	**2,437**	**5,491**

3 MONTHS AFTER STUDY RLR VIOLATIONS

Treatment Sites

3 Months after Study at 23rd Street & Louisiana Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2			2		7:15
2	1	1			2		8:53
3	1	1				2	7:53
4	1	1				1	8:56
5	1	2		3			7:03
6	1	1		3			7:44
7	1	2		3			8:07
8	1	2		3			8:33
9	1	1	2				7:39
10	1	1	3				8:43
11	1	1	3				8:51
12	1	1	3				8:53

3 Months after Study at 23rd Street & Louisiana Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		5:17
2	1	1				2	4:09
3	1	7				2	4:41
4	1	1				1	5:08
5	1	1				1	5:25
6	1	2				3	5:34
7	1	1				2	5:39
8	1	1		1			4:30
9	1	1		3			4:40
10	1	2		3			5:50
11	1	1	1				4:04
12	1	1	4				4:44
13	1	3	4				4:44
14	1	3	1				5:21
15	1	1	2				5:39

3 Months after Study at 23rd Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1				2	7:39
2	1	1				2	7:51
3	1	2				2	8:03
4	1	1				2	8:19
5	1	1				2	8:25
6	1	1				1	8:27
7	1	35			3		7:02
8	1	1			1		7:37
9	1	2			1		7:51
10	1	1			2		7:51
11	1	1			2		7:55
12	1	1			1		8:13
13	1	1			3		8:23
14	1	1			3		8:53
15	1	1			3		8:58
16	1	22			3		8:59

3 Months after Study at 23rd Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	2	1				4:45
2	1	3		1			4:09
3	1	2		1			4:12
4	2	2		1			5:02
5	1	2		1			5:14
6	1	1		1			5:49
7	1	1		9			5:57
8	1	1		9			5:57
9	1	3		9			5:57
10	1	3		9			5:57
11	1	1				1	4:01
12	1	1				1	4:16
13	1	1				2	4:42
14	1	1				1	4:53
15	1	1				1	5:38
16	1	1				6	4:08
17	1	4				6	4:08
18	1	7				6	4:08
19	1	10				6	4:08
20	1	2				3	4:15
21	1	3				3	5:23
22	1	2				2	5:32
23	1	5				3	5:46
24	1	1				1	5:47

1 Month after Study Traffic Volume at Treatment Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
23rd Street & Iowa Street	Morning Peak	NB	150	960	-	1,110
		SB	329	526	-	855
		WB	209	867	-	1,076
		EB	486	1,398	117	2,001
		Total	**1,174**	**3,751**	**117**	**5,042**
	Evening Peak	NB	243	896	-	1,139
		SB	493	1,185	-	1,678
		WB	519	1,497	-	2,016
		EB	341	1,212	284	1,837
		Total	**1,596**	**4,790**	**284**	**6,670**
23rd Street & Louisiana Street	Morning Peak	NB	109	436	248	793
		SB	145	257	165	567
		WB	173	1,512	161	1,846
		EB	211	1,537	70	1,818
		Total	**638**	**3,742**	**644**	**5,024**
	Evening Peak	NB	242	530	367	1,139
		SB	220	655	249	1,124
		WB	511	2,070	83	2,664
		EB	256	1,991	146	2,393
		Total	**1,229**	**5,246**	**845**	**7,320**

Control Sites

3 Months after Study at 6th Street & Kasold Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1			3		7:00
2	1	1			2		7:20
2	1	3			3		7:20
3	1	1			2		8:00
4	2	1			2		8:08
5	1	9			3		8:14
6	1	1			2		8:18
7	1	1				2	7:47
8	1	1				1	7:53
9	1	15		1			8:13
10	1	1		2			8:32
11	1	78	3				7:20
12	1	1	1				7:37

3 Months after Study at 6th Street & Kasold Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1	2				5:43
2	1	1			2		4:56
3	1	12			6		4:13
4	1	15			6		4:13
5	1	6			3		4:21
6	1	17			3		4:21
7	1	21			3		4:25
8	1	33			3		4:27
9	1	30			3		4:47
10	1	9			3		4:57
11	1	44			3		5:15
12	1	35			3		5:17
13	1	36			3		5:21
14	1	20			3		5:25
15	1	15			3		5:27
16	1	21			3		5:29
17	1	19			3		5:35
18	1	30			3		5:35
19	1	6			3		5:39
20	1	21			3		5:39
21	1	50			3		5:49
22	1	46			3		5:53
23	1	9			3		5:55
24	1	6			6		5:57
25	1	10			6		5:57
26	1	14			6		5:57

3 Months after Study at 31st Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	22			3		7:16
2	1	14			3		7:17
3	1	4			3		7:27
4	1	20			3		7:37
5	1	22			3		7:55
6	1	47			3		7:59
7	1	21				3	7:12
8	1	9				3	7:25
9	1	1				3	7:40
10	1	2				3	7:44
11	1	27				6	7:48
12	1	29				6	7:48
13	1	39				3	8:22
14	1	30				3	8:27
15	1	13	3				7:21
16	1	3		3			7:13
17	1	1		2			8:22
18	1	4		3			8:31

3 Months after Study at 31st Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1	1				4:48
2	1	1	3				5:04
3	1	51	3				5:58
4	1	1		3			4:02'
5	1	6		3			4:05
6	1	2		6			4:07
7	1	4		6			4:07
8	1	1		3			5:40
9	1	77				3	4:23
10	1	1				3	4:26
11	1	2				3	4:31
12	1	1				3	4:41
13	1	1				3	5:18
14	1	1				6	5:21
15	1	2				6	5:21
16	1	48				3	5:22
17	1	39			3		4:03
18	1	33			3		4:18
19	1	73			3		4:25
20	1	39			3		5:14
21	1	77			3		5:34

3 Months after Study at 6th Street & Michigan Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1				2	8:16
2	1	1			2		7:11
3	1	1			2		7:37
4	1	1			2		7:53
5	1	1			1		8:01
6	1	1			3		8:30
7	1	1			2		8:34
8	1	1			2		8:46
9	1	32	3				8:19
10	1	33		3			7:14

3 Months after Study at 6th Street & Michigan Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		4:11
2	1	1			2		4:25
3	1	1			2		4:57
4	1	1			2		5:55
5	1	4				3	4:09
6	1	1				2	4:34
7	1	1				2	4:42
8	1	2				3	4:48
9	1	2	3				5:14
10	1	32	3				5:58

3 Months after Study at 6th Street & Wakarusa Drive (Morning)

Number of vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	3				2	8:37
2	1	2	2				7:20
3	1	3	3				7:23
4	1	3	3				7:29
5	1	2	3				7:39
6	1	1	2				8:34
7	1	26	1				8:43
8	1	20	3				8:57
9	1	1		3			8:47

3 Months after Study at 6th Street & Wakarusa Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	12			3		4:55
2	1	22			3		4:55
3	1	16			3		5:13
4	1	1				8	5:00
5	1	1				8	5:00
6	1	1				2	5:22
7	1	2	3				5:41

3 Months after Study at Clinton Parkway & Kasold Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	2				3	7:30
2	1	2				3	7:40
3	1	18				6	7:46
4	1	19				6	7:46
5	1	24				3	7:46
6	1	1				2	8:16
7	1	2				3	8:18
8	1	9				3	8:18
9	1	17				3	8:32
10	1	40				1	8:39
11	1	36			3		7:30
12	1	1			2		7:43
13	1	1			3		7:49
14	1	1			1		8:36
15	1	1	2				7:11
16	1	9	3				8:10
17	1	12	3				8:58
18	1	1		2			7:28
19	1	1		1			8:11
20	1	1		2			8:21

3 Months after Study at Clinton Parkway & Kasold Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		4:48
2	1	1			1		5:12
3	1	2			6		5:17
4	1	5			6		5:17
5	1	1			1		5:22
6	1	1			1		5:26
7	1	1			5		5:28
8	1	2			5		5:28
9	1	1				2	4:15
10	1	1				2	4:25
11	1	1				1	5:09
12	1	1				1	5:33
13	1	1				1	5:39
14	1	1				1	5:41
15	1	1				1	5:51
16	1	1	1				4:06
17	1	1	3				4:15
18	1	1		1			4:15
19	1	1		1			4:34

3 Months after Study Traffic Volume at Control Sites

Intersection	Period	Approach	Volume per lane			Volume per approach
			L	T	R	
6th Street & Kasold Drive	Morning Peak	NB	262	199	396	857
		SB	220	370	104	694
		WB	212	1,120	47	1,379
		EB	61	1,447	258	1,766
		Total	**755**	**3,136**	**805**	**4,696**
	Evening Peak	NB	481	400	394	1,275
		SB	129	373	74	576
		WB	233	1,222	61	1,516
		EB	113	1,440	332	1,885
		Total	**956**	**3,435**	**861**	**5,252**
6th Street & Michigan Street	Morning Peak	NB	81	68	19	168
		SB	415	63	94	572
		WB	8	1,366	179	1,553
		EB	81	1,801	31	1,913
		Total	**585**	**3,298**	**323**	**4,206**
	Evening Peak	NB	126	99	41	266
		SB	460	62	195	717
		WB	30	2,266	251	2,547
		EB	56	1,897	63	2,016
		Total	**672**	**4,324**	**550**	**5,546**
31st Street & Iowa Street	Morning Peak	NB	90	777	148	1,015
		SB	71	344	123	538
		WB	122	276	165	563
		EB	193	379	119	691
		Total	**476**	**1,776**	**555**	**2,807**
	Evening Peak	NB	282	993	207	1,482
		SB	391	1,124	437	1,952
		WB	242	558	272	1,072
		EB	403	588	308	1,299
		Total	**1,318**	**3,263**	**1,224**	**5,805**
6th Street & Wakarusa Drive	Morning Peak	NB	250	318	430	998
		SB	189	225	60	474
		WB	411	607	103	1,121
		EB	50	651	192	893
		Total	**900**	**1,801**	**785**	**3,486**
	Evening Peak	NB	282	277	536	1,095
		SB	204	255	52	511
		WB	525	730	226	1,481
		EB	68	850	231	1,149
		Total	**1,079**	**2,112**	**1,045**	**4,236**
Clinton parkway & Kasold Drive	Morning Peak	NB	155	423	185	763
		SB	536	436	167	1,139
		WB	104	848	461	1,413
		EB	247	1434	198	1,879
		Total	**1,042**	**3,141**	**1,011**	**5,194**
	Evening Peak	NB	280	605	197	1,082
		SB	669	760	282	1,711
		WB	216	1,544	892	2,652
		EB	217	1,288	298	1,803
		Total	**1,382**	**4,197**	**1,669**	**7,248**

Spillover Sites

3 Months after Study at 23rd Street & Alabama Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1			2		7:05
2	1	1			1		7:05
3	1	1			2		7:05
4	1	1			2		7:05
5	1	1				2	6:54
6	1	1				2	6:54
7	1	1				2	6:54
8	1	2				2	6:54

3 Months after Study at 23rd Street & Alabama Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1	3				3:46
2	1	13	3				3:46
3	1	1				1	0:00
4	1	1			2		3:48
5	1	1			2		3:48
6	1	1			2		3:48
7	1	1			2		3:48
8	1	1			2		3:48

3 Months after Study at 19th Street & Louisiana Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	5			3		7:30
2	1	96			3		7:34
3	1	1			2		7:46
4	1	1			3		7:50
5	1	1				1	7:41
6	1	1	3				7:07
7	1	30	3				7:13
8	1	1	3				8:39
9	1	32	3				8:46
10	1	157		3			7:24

3 Months after Study at 19th Street & Louisiana Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1				1	4:12
2	1	1				2	4:26
3	1	1				1	5:23
4	1	1				1	5:29
5	1	1				1	5:34
6	1	1				1	5:37
7	1	1				1	5:47
8	1	3	3				4:15
9	1	1	3				5:37
10	1	1	3				5:50

3 Months after Study at 25th Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	20			3		7:35
2	1	1		2			7:53
3	1	1		2			8:03
4	1	1		2			8:19
5	1	1		2			8:29
6	1	1		2			8:33

3 Months after Study at 25th Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1	2				4:43
2	1	1	2				4:46
3	1	2		3			4:01
4	1	2		2			4:51
5	1	1		2			5:18
6	1	1		2			5:18
7	1	2		3			5:27

3 Months after Study at 19th Street & Iowa Street (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1	2				7:14
2	1	1	2				7:18
3	1	60	3				7:27
4	1	43	3				7:29
5	1	52	3				7:53
6	1	77	3				8:01
7	1	1	2				8:32
8	1	36	3				8:57
9	1	1		1			7:28
10	1	1		1			7:36
11	1	1		2			8:21

3 Months after Study at 19th Street & Iowa Street (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			1		5:55
2	1	1				1	4:58
3	1	1				1	5:35
4	1	31	1				4:02
5	1	60	1				4:37
6	1	1	1				4:56
7	1	1		2			4:30
8	1	1		2			4:53
9	1	1		5			4:55
10	1	2		5			4:55
11	1	3		5			4:55
12	1	1		2			5:10
13	1	1		2			5:20
14	1	1		2			5:55

3 Months after Study at 23rd Street & Ousdahl Road (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	1	1			2		7:02
2	1	1			2		7:58
3	1	2			1		8:04
4	1	1			2		8:20
5	1	1			2		8:24
6	1	1			2		8:46
7	1	1			2		8:48

3 Months after Study at 23rd Street & Ousdahl Road (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	1			2		5:09
2	1	1				2	4:37
3	1	1				2	5:37

3 Months after Study at Clinton Parkway & Crestline Drive (Morning)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m.)
1	2	1				2	8:10
2	1	1				3	8:50
3	1	2				3	8:57
4	1	39				3	8:58
5	1	4		3			8:08
6	1	28		3			8:11
7	1	31		3			8:22
8	1	2		3			8:53

3 Months after Study at Clinton Parkway & Crestline Drive (Evening)

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (p.m.)
1	1	2		3			4:57

3 Months after Study Traffic Volume at Spillover Sites

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
23rd Street & Ousdahl Road	Morning Peak	NB	50	78	29	157
		SB	57	82	146	285
		WB	44	1,290	42	1,376
		EB	232	1,596	36	1,864
		Total	**383**	**3,046**	**253**	**3,682**
	Evening Peak	NB	123	64	66	253
		SB	63	120	184	367
		WB	106	1,809	43	1,958
		EB	113	1,907	58	2,078
		Total	**405**	**3,900**	**351**	**4,656**
19th Street & Iowa Street	Morning Peak	NB	67	1,293	396	1,756
		SB	536	434	163	1,133
		WB	201	195	276	672
		EB	13	214	68	295
		Total	**817**	**2,136**	**903**	**3,856**
	Evening Peak	NB	108	1,339	339	1,786
		SB	251	1,629	25	1,905
		WB	614	290	371	1,275
		EB	60	270	156	486
		Total	**1,033**	**3,528**	**891**	**5,452**
19th Street & Louisiana Street	Morning Peak	NB	302	88	358	748
		SB	21	42	19	82
		WB	337	857	27	1,221
		EB	10	540	164	714
		Total	**670**	**1,527**	**568**	**2,765**
	Evening Peak	NB	213	103	515	831
		SB	92	197	22	311
		WB	630	1,076	16	1,722
		EB	17	894	192	1,103
		Total	**952**	**2,270**	**745**	**3,967**
Clinton Parkway & Crestline Drive	Morning Peak	NB	61	17	84	162
		SB	7	9	32	48
		WB	60	1,045	89	1,194
		EB	306	2,054	91	2,451
		Total	**434**	**3,125**	**296**	**3,855**
	Evening Peak	NB	162	11	71	244
		SB	122	18	245	385
		WB	98	2,343	36	2,477
		EB	46	1,677	105	1,828
		Total	**428**	**4,049**	**457**	**4,305**

3 Months after Study Traffic Volume at Spillover Sites (Continuation)

Intersection	Period	Approach	Volume per lane			Volume per Approach
			L	T	R	
25th Street & Iowa Street	Morning Peak	NB	42	1,143	9	1,194
		SB	28	648	50	726
		WB	16	11	45	72
		EB	73	22	35	130
		Total	**159**	**1,824**	**139**	**2,122**
	Evening Peak	NB	69	1,283	21	1,373
		SB	52	1,442	69	1,563
		WB	123	55	63	241
		EB	67	59	53	179
		Total	**311**	**2,839**	**206**	**3,356**
23rd Street & Alabama Street	Morning Peak	NB	41	54	50	145
		SB	21	23	24	68
		WB	60	1,698	18	1,776
		EB	82	1,850	67	1,999
		Total	**204**	**3,625**	**159**	**3,988**
	Evening Peak	NB	155	49	133	337
		SB	32	72	66	170
		WB	133	2,367	46	2,546
		EB	73	2,395	143	2,611
		Total	**393**	**4,883**	**388**	**5,664**

APPENDIX C

Press Releases

THE UNIVERSITY DAILY KANSAN

TUESDAY, SEPTEMBER 10, 2013 PAGE 2

What's the weather, Jay?

— weather.com

Wednesday

HI: 97
LO: 68

Mostly sunny. 10 percent chance of rain. Wind SW at 11 mph.

Last day of insta-sweat.

Thursday

HI: 84
LO: 62

Isolated t-storms. 30 percent chance of rain. Wind NE at 6 mph.

There is a God.

Friday

HI: 82
LO: 59

Mostly cloudy. Zero percent chance of rain. Wind ENE at 8 mph.

Still thankful.

N news

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Calendar

Tuesday, Sept. 10

What: Study Abroad Fair
When: 10:30 a.m. to 3:30 p.m.
Where: Kansas Union, 4th Floor
About: Programs table and coordinators talk one-on-one with students interested in studying abroad

What: SUA Presents: Open Mic Night
When: 7 p.m.
Where: Kansas Union, Alderson Auditorium
About: An entertainment contest for a cash prize open to students

Wednesday, Sept. 11

What: Volunteer Fair
When: 10 a.m. to 2 p.m.
Where: Kansas Union, 4th Floor
About: Volunteer clubs and local programs table in the lobby to give information on volunteer opportunities

What: Queering the Bible
When: 7 to 8 p.m.
Where: ECM Center, Main Floor
About: A presentation by Rev. Dwight Welch on being Christian and challenging social norms
Cost: Small donation requested for 6:30 p.m. dinner

Thursday, Sept. 12

What: The Role of Islam in Post-9/11 America
When: 7:30 to 9 p.m.
Where: Kansas Union, Woodruff Auditorium
About: A lecture by Arsalan Iftikhar, international human rights lawyer and author

What: Sexy Science
When: 5:30 to 7:30 p.m.
Where: Dyche Hall
About: Games, activities and snacks for KU students 18 years or older. Maybe you'll learn a thing or two.

Friday, Sept. 13

What: Sand Volleyball Tournament
When: 4 to 7 p.m.
Where: Ambler Student Recreation Fitness Center, Sand Volleyball Courts
About: Six-person team or club tournament for cash prizes, presented by Student Union Activities

CITY

Blue traffic light causes drivers to be cautious

JENNIFER SALVA
jsalva@kansan.com

There is a new color of traffic light at the intersections of 23rd and Iowa and 23rd and Louisiana streets. But it does not mean drivers have to do anything differently—except be more cautious.

These small blue lights fixed above the regular traffic colors help police officers determine if a driver passes through a red light.

The light does not contain sensors or cameras, but simply turns on with the red stoplight. This allows police officers to determine if a light is red from any vantage point in the intersection.

The new tool will potentially increase the enforcement of red light violators, according to Sergeant Trent McKinley, spokesperson for the Lawrence Police Department.

"We can park in an area where we can see the blue light, and merge into traffic to stop the violator," McKinley said.

This is easier than crossing through a red light to pull over a driver, McKinley said. He also said the blue lights could cause drivers to be more careful.

"You see a lot more people hitting the breaks," McKinley said. "Maybe they would be more careful about running the so-called yellow light."

Eric Fitzsimmons, a post-doctoral researcher at the University Transportation Research Institute was a key developer of the blue light project. The project is funded by the Kansas Department of Transportation and the Mid-America Transportation Center at the University of Nebraska Lincoln. It includes two intersections in Lawrence and two in Overland Park, Fitzsimmons said.

The two intersections chosen for the project, which are intersections with frequent red light running, were selected by the city, Lawrence Police Department and Fitzsimmons' research team.

"Ultimately, this project is designed to help the city in hopefully reducing the number of serious intersection crashes that result from someone running a red light," Fitzsimmons said.

Trenton Corcoran, a senior from Ottawa, thought at first that those blue lights were to illuminate signage beside the traffic lights at night.

He is not concerned with the new traffic additions because he does not think that driving through red lights is a problem in Lawrence.

"I guess I'm impartial," Corcoran said. "I've lived in Lawrence two years now and I don't see a lot of red light running."

According to Fitzsimmons, students and staff should not be concerned with the new lights, especially if they do not run red lights, Fitzsimmons said.

"If you see a yellow light and don't think you can make it safely through the intersection, come to a stop and wait," Fitzsimmons said. "It's only 60 to 90 seconds—but we all know it feels like forever—but you could be saving a life."

—Edited by Heather Nelson

KANSAN PHOTO

The new lights found at 23rd and Iowa Streets and 23rd and Louisiana Streets will help enforce red light violations. The lights do not contain sensors or cameras.

KU Engineering Researchers Study System to Improve Intersection Safety

LAWRENCE - Researchers at the University of Kansas School of Engineering have partnered with the cities of Lawrence, Kan. and Overland Park, Kan., to increase safety at four busy intersections by reducing red light running violations and simplifying law enforcement efforts to monitor potential infractions.

The project is funded by the Kansas Department of Transportation and the Mid-America Transportation Center and is under the direction of Steven Schrock and Eric Fitzsimmons with the KU School of Engineering. Red light running at intersections with traffic signals continues to be a serious safety concern for Kansas drivers, pedestrians, and bicyclists. In 2011, the Federal Highway Administration reported 676 fatalities (10 percent of all signalized intersection crashes) were due to red light running in the United States that based on 2009 state highway agency crash data. Since automated enforcement by traffic camera is not used in Kansas, researchers will install a blue confirmation light system at the following intersections starting the first week of July:

- Iowa Street and 23rd Street in Lawrence
- Louisiana Street and 23rd Street in Lawrence
- College Boulevard and Quivira Road in Overland Park
- 75th Street and Metcalf Avenue in Overland Park

These intersections were selected based on recommendations from each city's public works department, police department and the KU research team.

The blue confirmation light system is a low-cost, non-invasive countermeasure that is designed to help police officers safely identify and pull over drivers who run a red light while sitting downstream of the intersection. Each traffic signal mast arm will have one or two blue lights, one adjacent to the left turn signal, the other next to the through signal. While the traffic signal is green, the blue lights remain off. The blue light comes on the moment the traffic signal turns red, so law enforcement officials monitoring an intersection can use the blue light as a visual cue. If it's illuminated, no cars from that movement should enter the intersection. The blue light is visible from 360 degrees, so officers will know a motorist has run a red light even if they cannot see the traffic signal change colors.

The goal is to reduce the number of officers needed to monitor an intersection and reduce the need to interrupt traffic to chase a violating vehicle through an intersection. KU School of Engineering researchers will evaluate the confirmation light system over the next six months and report effectiveness results to city and state officials. The system has shown promising results in similar communities located in Florida, Kentucky, Texas, and Minnesota.

"The School of Engineering is excited to partner with the cities of Lawrence and Overland Park in the effort to improve driver safety at these busy intersections," said Steve Schrock, associate professor of civil, environmental and architectural engineering at the University of Kansas. “We believe this system can be a valuable tool for law enforcement, while substantially reducing the instances of red light running and making the roads safer for everyone.”

Overland Park Police Chief John Douglass had this to say about the concept: “The safety of our citizens and the officers who serve them are paramount to what we do on a daily basis. This simple, yet innovative system will allow us to safely monitor and enforce traffic violations at two of the city’s busiest intersections in regard to traffic accidents”.

# # #